

CHAPTER 21

NUCLEAR PHYSICS

MULTIPLE CHOICE

- Rest mass of an electron is**
 A. 9.1×10^{-27} kg
 B. 9.1×10^{-28} kg
 C. 9.1×10^{-29} kg
 D. 9.1×10^{-31} kg
- A particle having the mass of an electron and charge of proton is called:**
 A. Photon
 B. Antiproton
 C. Positron
 D. Betatron
- Nuclei of different elements are identified by their:**
 A. Atomic number
 B. Mass number
 C. Nuclear charge
 D. None
- For an atom having atomic number Z and atomic mass ' A ' the number of neutrons in the nucleus is:**
 A. $A + Z$
 B. A
 C. $A - Z$
 D. Z
- Nuclear force exists between:**
 A. Neutron-neutron
 B. Proton-proton
 C. Proton-Neutron
 D. All
- The amount of energy required to break the nucleus is called its:**
 A. Atomic energy
 B. Nuclear energy
 C. Binding energy
 D. Kinetic energy
- When an alpha particle collides with an atom of a gas, it knocks out:**
 A. neutrons
 B. protons
 C. electrons
 D. positrons
- Nuclei of different elements are identified by their**
 A. atomic mass number
 B. atomic number
 C. nuclear mass
 D. nuclear charge
- Beta particles possess greater penetration power than that of alpha particles due to their**
 A. smaller ionization power
 B. greater ionization power
 C. neither greater nor smaller ionization power
 D. the same ionization power
- The diameter of an atom is approximately equal to**
 A. 10^{-12} m
 B. 10^{-11} m
 C. 10^{-10} m
 D. 10^{-15} m
- Atomic mass unit (u) is used to measure the**
 A. mass
 B. length
 C. time
 D. none of these

12. 1 amu (u) is equal to 1.66 ×
 A. 10^{-27} kg B. 10^{-31} kg C. 10^{-4} kg D. 10^{-34} kg
13. The mass of Beta particle is equal to the mass of
 A. electron B. proton C. Neutron D. Boson
14. Sub atomic particles are divided into
 A. Photons B. Leptons
 C. Hadrons D. All of these
15. The amount of energy equivalent to 1 a.m.u is:
 A. 9.315 Mev B. 93.15 Mev
 C. 931.5 Mev D. 0.931 Mev
16. α , β and γ are emitted from a radio-active substance:
 A. When heated B. When exposed to light
 C. When it interacts with other particles D. Spontaneously
17. The time taken for radioactive element to decay to half of its original number of atoms:
 A. Average life B. Half life
 C. Total life D. Decay constant
18. The reciprocal of decay constant λ of radioactive element is:
 A. Half life B. Mean life C. Total life D. None
19. A pair of quark and anti-quark makes a
 A. Meson B. Baryon C. Photon D. Proton
20. Abdus Salam forwarded theory of unification of
 A. Electromagnetic and weak force
 B. Electromagnetic and strong nuclear force
 C. Electromagnetic and gravitational force
 D. Electric and magnetic forces
21. The building blocks of protons & neutrons are,
 A. Ions B. Electrons C. Positrons D. Quarks
22. A detector which can count fast and operate at low voltage is
 A. G.M. Counter B. Solid state detector
 C. Wilson cloud chamber D. Bubble chamber
23. The half-life of radioactive element depends on:
 A. Temperature
 B. Pressure
 C. Nature of element
 D. Amount of radioactive substance
24. The radioactive decay obeys the law:
 A. $N_0 = N(1 + e^{\lambda t})$ B. $N = N_0 e^{\lambda t}$
 C. $N = N_0 e^{-\lambda t}$ D. $N_0 = N e^{-\lambda t}$
25. The rate of decay of radioactive substance:
 A. Is constant
 B. Decreases exponentially with time
 C. Varies inversely with time
 D. Decreases linearly with time

26. The process in which heavy nucleus is broken into two intermediate nuclei with release of energy is called:
 A. Fission B. Fusion
 C. Nuclear reaction D. Chemical reaction
27. Fission reaction in U^{238} is produced by:
 A. Thermal neutrons B. Slow neutrons
 C. Fast neutrons D. None
28. The most useful tracer isotope is
 A. Carbon-14 B. Cobalt-60
 C. Iodine-131 D. Strontium-90
29. The process in which a heavy nucleus splits into lighter nuclei is known as
 A. Fission B. Fusion
 C. a chain reaction D. α -decay
30. Controlled fission chain reaction is maintained in a:
 A. Nuclear reactor B. Cyclotron
 C. Betatron D. A C Generator
31. The moderator used in nuclear reactor is:
 A. Aluminium B. Sodium
 C. Calcium D. Graphite
32. Which one of the following bomb is more destructive?
 A. Atom bomb B. Hydrogen bomb
 C. Neutron bomb D. Biological bomb
33. The chemical properties of an element depend only upon the number of
 A. Protons B. neutrons
 C. electrons D. mesons

Answers:

1. D	2. C	3. A	4. C	5. D	6. C	7. C
8. B	9. A	10. C	11. A	12. A	13. A	14. D
15. C	16. D	17. B	18. B	19. A	20. A	21. D
22. B	23. C	24. C	25. B	26. A	27. C	28. A
29. A	30. A	31. D	32. B	33. A		

SHORT & LONG QUESTIONS

Q1: What do you understand by atomic nucleus? Describe its composition also?

Ans: Atomic nucleus:

- At the centre of each and every atom there is an infinitesimally small nucleus. The entire positive charge of the atom and about 99.9 percent of its mass is concentrated in the nucleus.
- The tininess of the nucleus can be imagined by comparing that the radius of the atom is 10^5 times the radius of the nucleus.

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Composition of nucleus:

- A nucleus consists of nucleons comprising of protons and neutrons.
- A proton has a positive charge equal to $1.6 \times 10^{19} \text{C}$ and its mass is $1.673 \times 10^{-27} \text{kg}$.
- A neutron has no charge on it, but its mass is $1.675 \times 10^{-27} \text{kg}$. The mass of a neutron is almost equal to mass of proton.

Q2: Define unified mass scale (u)?

Ans: To indicate the mass of atomic particles, instead of kilogram, unified mass scale (u) is generally used.

Unified mass scale (u):

By definition 1u is exactly one twelfth the mass of carbon¹² (C^{12}) atom ($1 \text{ u} = 1.6606 \times 10^{-27} \text{ kg}$).

In this unit the mass of a proton is 1.007276 u and that of a neutron is 1.008665 u while that of an electron is 0.00055 u.

Q3: Define atomic number and mass number?

Ans: Atomic number or charge number:

The number of protons inside a nucleus is called the atomic number or the charge number of an atom. It is denoted by Z. Thus the total charge of any nucleus is Ze; here "e" indicates charge on one proton.

Mass number (A):

The combined number of all the protons and neutrons in a nucleus is known as its mass number and is denoted by A.

Note:

The number of neutrons N present in a nucleus is given by

$$N = (A - Z) \quad \dots\dots\dots (1)$$

Q4: What are isotopes? What do they have in common and what are their differences?

Ans: Isotopes:

Isotopes are such nuclei of an element that have the same charge number Z, but have different mass number A.

Similarities and differences of isotopes:

In the nucleus of isotopes the number of protons is the same, but the number of neutrons is different.

Q5: Describe the isotopes of helium and hydrogen?

Ans: Isotopes of helium:

Helium, has two isotopes. These are symbolically represented as ${}^3_2\text{He}$ and ${}^4_2\text{He}$. As the charge number of helium is 2, therefore, there are two protons in the helium nucleus. The neutron number of the first isotope is $3 - 2 = 1$ and that in the second isotope ${}^4_2\text{He}$, the number of neutron is $4 - 2 = 2$.

Isotopes of hydrogen:

Hydrogen has three isotopes represented by ${}^1_1\text{H}$, ${}^2_1\text{H}$, ${}^3_1\text{H}$.

i. **Ordinary hydrogen or protium (${}^1_1\text{H}$):**

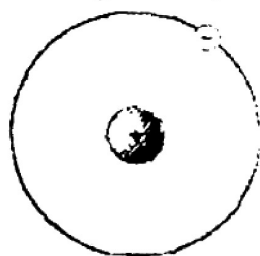
Its first isotope is called ordinary hydrogen or protium. There is only one proton in its nucleus.

ii. **Deuterium (${}^2_1\text{H}$):**

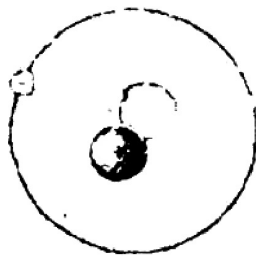
The second isotope of hydrogen is called deuterium. It has one proton and one neutron in its nucleus. Its nucleus is called deuteron.

iii. **Tritium (${}^3_1\text{H}$):**

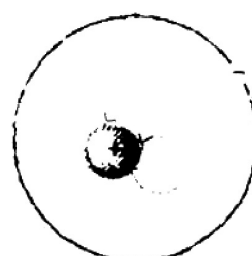
The third isotope of hydrogen has two neutrons and one proton in its nucleus and it is called tritium.



${}^1_1\text{H}$
(Protium)



${}^2_1\text{H}$
(Deuterium)



${}^3_1\text{H}$
(Tritium)

Q6: Why it is not possible to separate the isotopes of an element by chemical methods? Name the device which is used to separate isotopes?

Ans: i. The chemical properties of all the isotopes of an element are alike, as the chemical properties of an element depend only upon the number of electrons around the nucleus that is upon the charge number Z , which for all the isotopes of an element is the same. It is, therefore, not possible to separate the isotopes of an element by chemical methods.

ii. **Mass spectrograph:**

Physical methods are found to be successful for this purpose. A device with the help of which not only the isotopes of any element can be separated from one another but their masses can also be determined quite accurately is called mass spectrograph.

Q7: How much isotopes have xenon and cesium?

Ans: Both Xenon and cesium each have 36 isotopes.

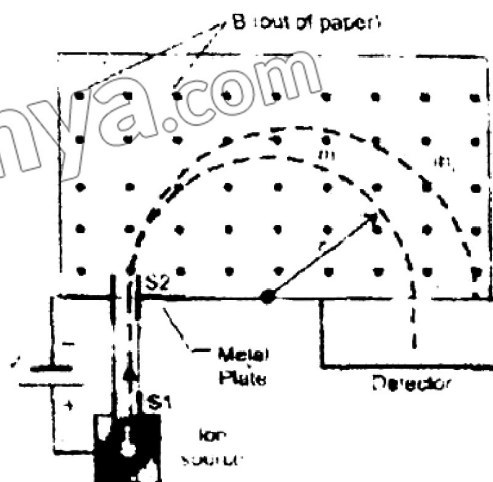
Q8: How mass spectrograph can be used for the detection of isotopes? OR Describe the construction and working of mass spectrograph?

Ans: Mass spectrograph:

A device with the help of which not only the isotopes of any element can be separated from one another but their masses can also be determined quite accurately is called mass spectrograph.

Construction and working of mass spectrograph:

i. The atoms or molecules of the element under investigation, in vapour form, are ionized in the ion source S . As a result of ionization, one electron is removed from the particle leaving with a net positive charge $+e$.



- ii. The positive ions escaping the slit S_1 are accelerated through a potential difference V applied between the two slits S_1 and S_2 .
- iii. **The K.E. of singly charged ion at the slit S_2 :**
The ions pass through the slit S_2 in the form of a narrow beam. The K.E. of singly charged ion at the slit S_2 will be given by

$$\frac{1}{2}mv^2 = Ve \quad \dots\dots\dots (1)$$

iv. **Application of magnetic field (B):**

The ions are then subjected to a perpendicular and uniform magnetic field B in a vacuum chamber, where they are deflected in semicircular paths towards a detector. The detector records the number of ions arriving per second. The centripetal force applied by the magnetic field is given by

$$Bev = \frac{mv^2}{r} \quad \dots\dots\dots (2)$$

$$m = \frac{Ber}{v}$$

Substituting the values of v from Eq. 1, we get

$$m = \left(\frac{er^2}{2V}\right) B^2 \quad \dots\dots\dots (3)$$

The above equation shows that the mass of each ion reaching the detector is proportional to B^2 i.e.

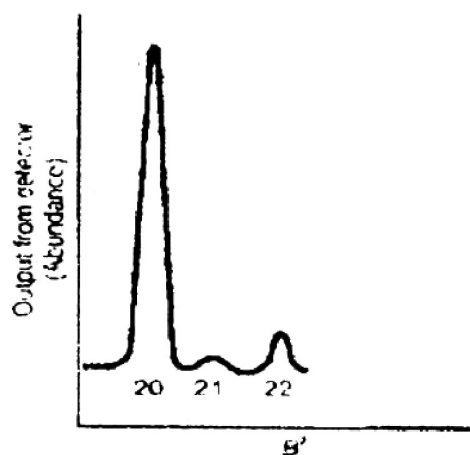
$$m \propto B^2$$

v. **Graph of the detector output as a function of B^2 :**

By adjusting the value of B and keeping the term in the parentheses constant, ions of different masses are allowed to enter the detector. A graph of the detector output as a function of B^2 then gives an indication of what masses are present and the abundance of each mass.

Detection of most abundant isotope:

Fig. shows a record obtained for naturally occurring neon gas showing three isotopes whose atomic mass numbers are 20, 21, and 22. The larger is the peak, the more abundant is the isotope. Thus most abundant isotope of neon is neon-20.



Q9: Explain mass defect and binding energy in detail with the help of examples and graphs?

Ans: Mass defect:

The mass of the nucleus is always less than the total mass of the protons and neutron that make up the nucleus. The difference of the two masses is called mass defect.

Binding energy:

The missing mass is converted to energy in the formation of the nucleus and is called the binding energy.

Explanation:

In the nucleus the missing mass is called the mass defect m given by

$$\Delta m = Zm_p + (A - Z)m_n - m_{\text{nucleus}} \quad \dots\dots\dots (1)$$

Here Z	=	total number of protons in the nucleus
m_p	=	The mass of a proton
Zm_p	=	The total mass of all the protons
$(A - Z)$	=	The total number of neutrons
m_n	=	The mass of a single neutron
$(A - Z)m_n$	=	The total mass of all the neutrons.
m_{nucleus}	=	The experimentally measured mass of the entire nucleus.

Note: Hence, Eq. 1 represents the difference in mass between the sum of the masses of its constituents and the mass of the nucleus itself.

Binding energy (B.E) of the nucleus:

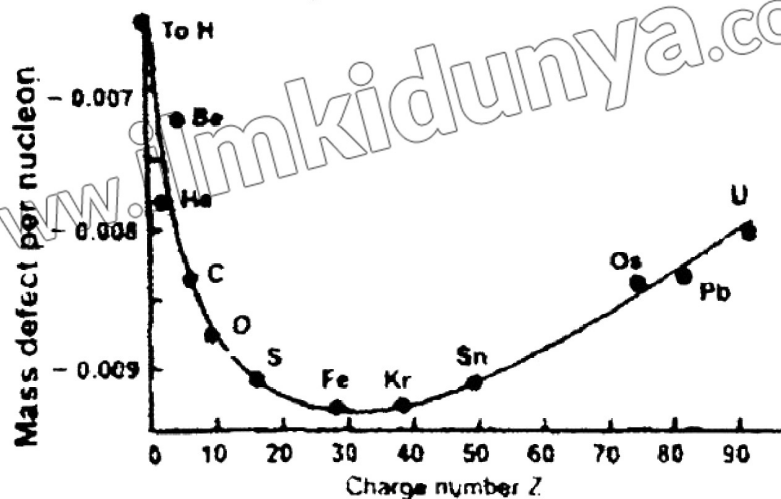
The missing mass is converted to energy in the formation of the nucleus. This energy is found from Einstein's mass energy relation and is called the binding energy (B.E.) of the nucleus

$$E = (\Delta m) c^2 \quad \text{..... (2)}$$

From equations 1 and 2, the binding energy of a nucleus is

$$\text{B.E.} = (\Delta m) c^2 = Zm_p c^2 + (A - Z) m_n c^2 - m_{\text{nucleus}} c^2 \quad \text{..... (3)}$$

Graph between the mass defect per nucleon and charge number Z:



Graph between the mass defect per nucleon and charge number Z is obtained by finding the difference of mass between the total mass of all the protons and neutrons that form the nucleus and the experimental mass of the nucleus and dividing this difference by mass number A, i.e., Mass defect per nucleon

$$\frac{\Delta m}{A} = \frac{m_{\text{nucleus}} - [Zm_p + (A - Z)m_n]}{A}$$

where Δm is the mass defect.

Mass defect of hydrogen:

From the definition of mass defect it is quite obvious that for hydrogen, mass defect is zero

Note: The mass defect is made clear with Einstein's equation

$E = \Delta m c^2$. This equation shows that if for any reason a mass Δm is lost, then it is converted into energy.

B.E. of helium:

Let us now calculate the B.E. of helium. For ${}^4_2\text{He}$

$$\Delta m = 2m_p + 2m_n - m_{\text{He}} = 2 \times 0.01519 + 2 \times 0.01796 - 4.0028 = 0.03034 \text{ u}$$

$$\text{since } 1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$$

$$\Delta m = 0.03034 \text{ u} \times 1.66 \times 10^{-27} \text{ kg u}^{-1} = 5.03 \times 10^{-29} \text{ kg}$$

Thus $BE = \Delta mc^2 = 5.03 \times 10^{-29} \times 9 \times 10^{16} = 4.5 \times 10^{-12} \text{ J} = \frac{4.5 \times 10^{-12}}{1.6 \times 10^{-19}} = 2.82 \times 10^7 \text{ eV} = 28.2 \text{ MeV}$

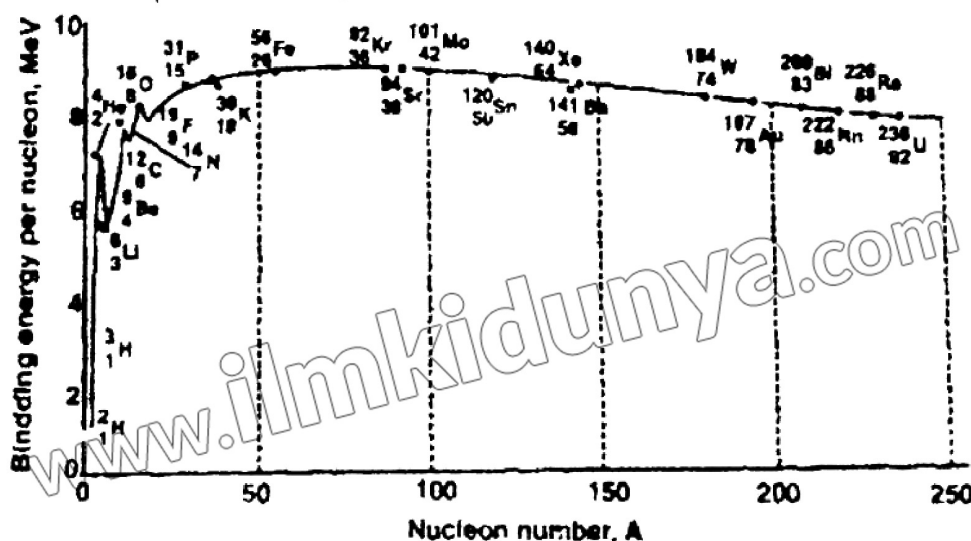
This means that when two protons and two neutrons fuse together to make helium nucleus, if an amount of 28.2 MeV energy is given to the helium nucleus then it breaks up into two protons and two neutrons.

From this, we conclude that

$$1 \text{ u} = 1.6606 \times 10^{-27} \text{ kg} = 931 \text{ MeV}$$

Graph between binding energy per nucleon and the mass number of different elements:

This graph shows that the binding energy per nucleon increases



with the mass number till it reaches a maximum value of 8.8 MeV at mass number 58 and then it gradually decreases to a value of 7.6 MeV at mass number 238. The binding energy per nucleon is maximum for iron. This shows that of all the elements iron is the most stable element.

Q10: What do you mean radioactivity? Discuss the properties of three types of radiations?

Ans: Radioactivity:

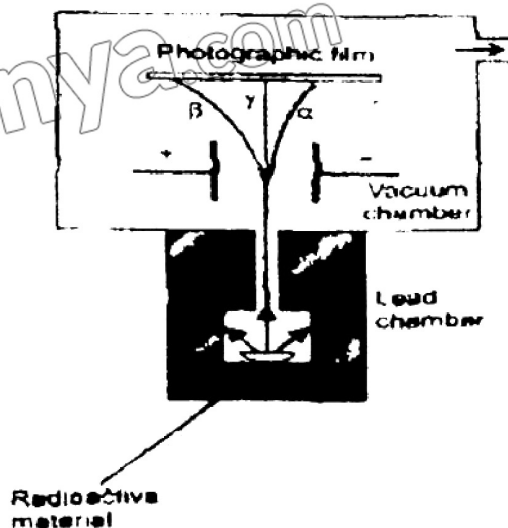
The emission of radiations (α , β and γ) from elements having charge number Z greater than 82 is called radioactivity.

Explanation:

It has been observed that those elements whose charge number Z is greater than 82 are unstable. Some invisible radiations, that can affect the photographic plates emanate out of these elements. Such elements are called radioactive and the phenomenon is called radioactivity.

Types of radiations:

The radiations coming out of the radioactive elements are called alpha (α), beta (β), and gamma (γ) radiation.



Discovery of radioactivity:

- i. Radioactivity was discovered by Henri Becquerel in 1896. He found that an ore containing uranium ($Z = 92$) emits an invisible radiation that penetrates through a black paper wrapping a photographic plate and affects the plate.
- ii. After Becquerel's discovery Marie Curie and Pierre Curie discovered two new radioactive elements that they called polonium and radium.

Analysis of the radiations emanating out of a radioactive material:

The analysis of the radiations emanating out of a radioactive material can be carried out by a simple experiment.

Experiment:

- i. The radioactive material is placed at the centre of a block of lead by drilling a hole in the block.
- ii. Radioactive radiations enter a vacuum chamber after emerging out of this hole. After passing between the two parallel plates the radiations strike a photographic plate.
- iii. These radiations, instead of impinging at one point, fall at three different points due to the potential difference between the plates.

Conclusions:

From this experiment it can be concluded that all radiations from the radioactive material are not alike.

i. α -particles:

The radiation that bends towards the negative plate is made up of positively charged particles. These are called α -particles.

Properties of α -particles:

α -particles are helium nuclei. The charge on them is $+2e$ while their mass is $4u$ (atomic mass unit) that is every α -particle has two protons and two neutrons in it.

ii. β -particles:

Those radiations that bend towards the positive plate are composed of negatively charged particles. These are called β -particles.

Properties of β -particles:

β -particles are in fact fast moving electrons which come out of the nucleus of a radioactive element.

iii. γ -particles:

Those radiations that go straight without bending have no charge on them. These are called γ -rays.

Properties of γ -particles:

γ -rays like X-rays, are electromagnetic waves which issue out of the nucleus of a radioactive element. The wavelength of these rays is much shorter, compared with the wavelength of X-rays.

Q11: What do you understand by nuclear transmutation or radioactive decay? Illustrate the mechanism of emission of α -particle, β -particle and γ -particle?

Ans: Nuclear transmutation or radioactive decay:

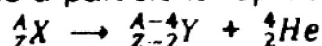
The change of an element into a new element due to emission of radiations is called radioactive decay. The original element is called parent element and the element formed due to this decay is called daughter element.

This phenomenon is called radioactive decay or nuclear transmutation.

Note: During the nuclear changes the laws of conservation of mass, energy, momentum and charge remain applicable.

α -decay or emission of α -particle:

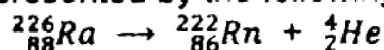
When an α -particle is emitted out of any nucleus then due to law of conservation of matter, the mass number of the nucleus decreases by 4, and due to law of conservation of charge, the charge of the nucleus decreases by a magnitude of $2e$ i.e., the charge number of the nucleus decreases by 2. It is due to the fact that the mass number and charge number of the emitted particle α is 4 and 2 respectively. The emission of the α -particle is represented by the following equation



Here X represents the parent and Y the daughter element.

Example:

To explain the emission of α -particles we take the example of radium ${}_{88}^{226}Ra$. The emission of an α -particle from radium 226, results in the formation of radon gas ${}_{86}^{222}Rn$. This change is represented by the following equation

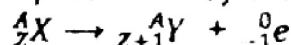


Note:

It may be remembered that the sum of the mass numbers and the charge numbers on both sides of the equation are equal.

β -decay or emission of β -particle:

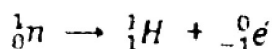
When a β -particle is emitted out of any nucleus, then its mass number does not undergo any change but its charge number increases by one. The emission of a β -particle from any element X is represented by the following equation



That is why at the time of emission of a β -particle the charge number of the nucleus increases by one but no change in its mass number takes place as the mass of electron is exceedingly small as compared to the mass of a proton or a neutron.

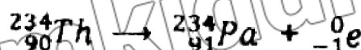
Transformation of an electron:

The transformation of an electron at the moment of its emission is given below by an equation



Example:

It has been observed that thorium ${}_{90}^{234}Th$ is transformed into protactinium ${}_{91}^{234}Pa$ after the emission of β -particle. The following equation represents this reaction



γ -decay or emission of γ -particle:

When a γ -radiation issues out of nucleus then neither the charge number Z nor the mass number A of the nucleus undergoes any change. It is due to the fact that a γ -radiation is simply a photon that has neither any charge nor any mass. Its emission from the nucleus has some resemblance with the emission of a photon of light from an atom.

The emission of γ -radiation from a nucleus is generally represented by this equation



Here ${}^A_ZX^*$ represents an excited nucleus while A_ZX shows ground state of the nucleus

Q12: Explain the phenomena of half life of a radioactive element. How a half life of a radioactive element can be determined?

Ans: Half life:

Half-life of a radioactive element is that period in which half of the atoms of the parent element decay into daughter element.

Explanation:

i. "The half-life $T_{1/2}$ of a radioactive element is that period in which half of the atoms decay".

ii. **Infinite time is required for complete decay:**

No radioactive element can completely decay. It is due to the reason that in any half-life period only half of the nuclei decay and in this way an infinite time is required for all the atoms to decay.

iii. The number of atoms decaying in a particular period is proportional to the number of atoms present in the beginning of the period. If the number of atoms to start with is large then a large number of atoms will decay in this period and if the number of atoms present in the beginning is small then less atoms will decay.

Measurement of half life.

If at any particular time the number of radioactive atoms be N , then in an interval Δt , the number of decaying atom ΔN is proportional to the time interval Δt and the number of atoms N . i.e.

$$\Delta N \propto -N \Delta t$$

Or

$$\Delta N = -\lambda N \Delta t \quad \dots \dots (1)$$

where λ is the constant of proportionality and is called decay constant.

Decay constant (λ):

$$\Delta N = -\lambda N \Delta t \quad \dots \dots (1)$$

Eq. 1 shows that if the decay constant of any element is large then in a particular interval more of its atoms will decay and if the constant λ is small then in that very interval less number of atoms will decay.

From Eq. 1 we can define decay constant λ as given below

$$\lambda = -\frac{\frac{\Delta N}{N}}{\Delta t}$$

here $\Delta N/N$ is the fraction of the decaying atoms. Thus decay constant of any element is equal to the fraction of the decaying atoms per unit time. The negative sign in the Eq. 1 indicates the decrease in the number of atoms N .

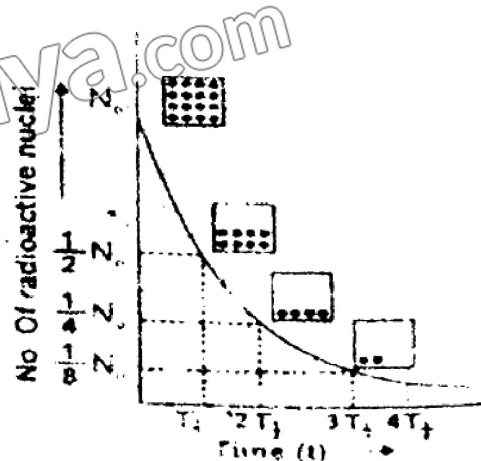
Unit of decay constant:

The unit of the decay constant is s^{-1} .

The decay ability of any radioactive element can be shown by a graphic method also.

Decay curve:

We know that every radioactive element decay at a particular rate with time. If we draw a graph between number of atoms in the sample of the radioactive element present at different times and the time then a curve as shown in Fig. will be



obtained. This graph shows that in the beginning the number of atoms present in the sample of the radioactive element was N_0 . With the passage of time the number of these atoms decreased due to their decay. This graph is called decay curve.

Explanation:

- i. After a period of one half-life $N_0/2$ number of atoms of this radioactive element is left behind. If we wait further for another half-period then half of the remaining $N_0/2$ atoms decay, and $1/2 \times N_0/2 = (1/2)^2 N_0$ atoms remain behind.
- ii. After the expiry of further period of a half-life, half of the remaining $(1/2)^2 N_0$ atoms decay. The number of atoms that remain un-decayed is $1/2 \times (1/2)^2 N_0 = (1/2)^3 N_0$.
- iii. We can conclude from this example that if we have N_0 number of any radioactive element then after a period of n half-lives the number of atoms left behind is $(1/2)^n N_0$.

For example:

The half-life of uranium-238 is 4.5×10^9 years while the half-life of radium-226 is 1620 years. The half-life of some radioactive elements is very small, for example, the half-life of radon gas is 3.8 days and that of uranium-239 is 23.5 minutes.

Relations exist between the decay constant λ and the half-life $T_{1/2}$:

$$\lambda T_{1/2} = 0.693 \quad (2)$$

Eq. 2 shows that if the decay constant λ of any radioactive element is known, its half-life can be found.

Q13: Explain briefly the interaction of radiation with matter?

Ans: Interaction of radiation with matter:

a. Interaction of α -particles with matter:

An α -particle travels a well defined distance in a medium before coming to rest. This distance is called the range of the particle. As the particle passes through a solid, liquid or gas, it loses energy due to excitation and ionization of atoms and molecules in the matter. The ionization may be due to direct elastic collisions or through electrostatic attraction. Ionization is the main interaction with matter to detect the particle or to measure its energy. The range depends on the

- i. charge, mass and energy of the particle and
- ii. The density of the medium and ionization potentials of the atoms of the medium.

Note:

Since α -particle is about 7000 times more massive than an electron, so it does not suffer any appreciable deflection from its straight path, provided it does not approach too closely to the nucleus of the atom. Thus α -particle continues producing intense ionization along its straight path till it loses all its energy and comes almost to rest. It then captures two electrons from the medium and becomes a neutral helium atom.

b. Interaction of β -particles with matter:

β -particles also lose energy by producing ionization. However, its ionizing ability is about 100 times less than that of α -particles. As a result its range is about 100 times more than α -particles. β -particles are more easily deflected by collisions than heavy α -particles. Thus the path of β -particles in matter is not straight but

shows much straggling or scattering. The range of β -particles is measured by the effective depth of penetration into the medium not by the length of erratic path. The more dense the material through which the particle moves, the shorter its range will be.

c. Interaction of γ -particles with matter:

Photons of γ -rays, being uncharged, cause very little ionization. Photons are removed from a beam by either scattering or absorption in the medium. They interact with matter in three distinct ways, depending mainly on their energy.

- (i) At low energies (less than about 0.5 MeV), the dominant process that removes photons from a beam is the photoelectric effect.
- (ii) At intermediate energies, the dominant process is Compton scattering.
- (iii) At higher energies (more than 1.02 MeV), the dominant process is pair production.

Note:

In air γ -rays intensity falls off as the inverse square of the distance from the source, in much the same manner as light from a lamp. In solids, the intensity decreases exponentially with increasing depth of penetration into the material.

Relation between the intensity I_0 and distance:

The intensity I_0 of a beam after passing through a distance x in the medium is reduced to intensity I given by the relation

$$I = I_0 e^{-\mu x}$$

Where μ is the linear absorption coefficient of the medium. This coefficient depends on the energy of the photon as well as on the properties of the medium.

Q14: Define fluorescence. Describe interaction of neutrons with matter?

Ans: Fluorescence:

"Fluorescence is the property of absorbing radiant energy of high frequency and re-emitting energy of low frequency in the visible region of electromagnetic spectrum."

Charged particles α or β and γ -radiation produce fluorescence or glow on striking some substance like zinc sulphide, sodium iodide or barium platinocyanide coated screens.

Interaction of neutron with matter:

Neutrons, being neutral particles, are extremely penetrating particles. To be stopped or slowed, a neutron must undergo a direct collision with a nucleus or some other particle that has a mass comparable to that of the neutron. Materials such as water or plastic, which contain more low-mass nuclei per unit volume, are used to stop neutrons. Neutrons produce a little indirect ionization when they interact with materials containing hydrogen atoms and knock out protons.

Q15: Illustrate the summary of nature of α, β, γ radiation?

Ans: Summary of the nature of α, β, γ radiation:

Characteristics	α -particles	β -particles	γ -rays
1. Nature	Helium nuclei of charge $2e$	Electrons or positrons from the nucleus of charge $\pm e$	E M waves from excited nuclei with no charge
2. Typical sources	Radon-222	Strontium-94	Cobalt-60
3. Ionization (Ion pairs mm^{-1} in air)	About 10^4	About 10^2	About 1
4. Range in air	Several centimetres	Several metres	Obeys inverse square law
5. Absorbed by	A paper	1~5 mm of Al sheet	1~10 cm of lead sheet
6. Energy spectrum	Emitted with the same energy	Variable energy	Variable energy
7. Speed	$\sim 10^7 \text{ ms}^{-1}$	$\sim 1 \times 10^8 \text{ ms}^{-1}$	$\sim 3 \times 10^8 \text{ ms}^{-1}$

Q16: What are the radiation detectors?

Ans: Radiation detectors:

i. Nuclear radiations cannot be detected by our senses, hence, we use some observable detecting methods employing the interaction of radiation with matter.

ii. **Principle of radiation detector:**

Most detectors of radiation make use of the fact that ionization is produced along the path of the particle

Types of radiation detectors:

These detectors include Wilson cloud chamber, Geiger counter and solid state detectors.

Q17: Explain briefly the construction and working of Wilson cloud chamber?

Ans: Wilson cloud chamber:

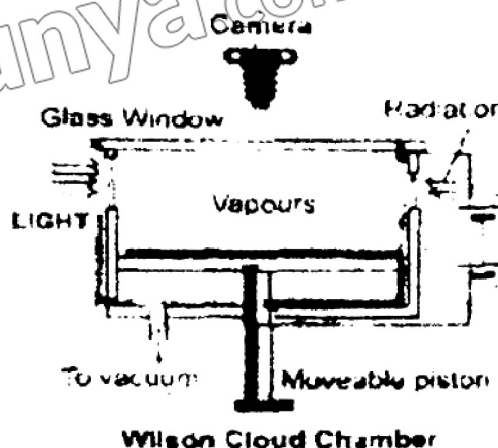
It is a device which shows the visible path of an ionizing particle. It makes use of the fact that supersaturated vapours condense preferentially on ions.

Construction and working of Wilson cloud chamber:

i. If an ionizing particle passes through a region in which cloud droplets are about to form, the droplets will form first along the particle's path, showing the path as a trail of droplets.

ii. **Cylindrical glass chamber:**

The apparatus consists of a cylindrical glass chamber closed at the upper end by a glass window and at the lower end by a movable piston.



iii. **Black felt pad:**

A black felt pad soaked in alcohol is placed on a metal plate inside the chamber. The air soon becomes saturated with alcohol vapours.

iv. **Bicycle pump:**

A rapid expansion is produced by pulling quickly the piston of the bicycle pump having the leather washer reversed so that it removes air.

v. **Adiabatic expansion:**

The sudden cooling resulted from adiabatic expansion helps to form supersaturated vapours.

vi. **Chamber:**

As radiation passes through the chamber, ions are produced along the path. The tiny droplets of moisture condense about these ions and form vapour tracks showing the path of the radiation.

vii. **Atomic versions of the ice crystals:**

These are the atomic versions of the ice crystals left in the sky by a jet plane when suitable conditions exist. The fog tracks are illuminated with a lamp and may be seen or photographed through the glass window.

viii. **Cloud chamber track of α -particle:**

The α -particles leave thick, straight and continuous tracks due to intense ionization produced by them as shown in Fig.

ix. **Cloud chamber track of β -particle:**

β -particles form thin and discontinuous tracks extending in erratic manner showing frequent deflections.

x. **Cloud chamber track of γ -particle:**

γ -rays leave no definite tracks along their path.

Length of cloud track:

The length of the cloud tracks has been found proportional to the energy of the incident particle.

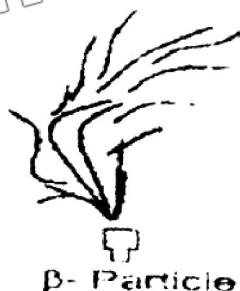
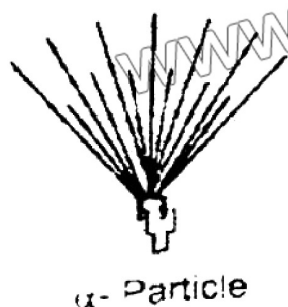
Application of high potential difference:

A high potential difference of the order of 1 kV between the top and bottom of the chamber provides an electric field which clears away all the unwanted ions from the chamber to make it ready for use. The tracks seen are, therefore, those of rays that pass the chamber as the expansion occurs.

Application of magnetic field:

The chamber may be placed in a strong magnetic field which will bend the paths providing information about the charge, mass and energy of the radiating particle. In this way, it has helped in the discovery of many new particles.

Cloud chamber tracks of α , β , γ radiations:



Q18: Explain briefly the construction and working of Geiger-Muller counters?

Ans: Geiger-Muller counters:

Geiger-Muller tube is a well-known radiation detector.

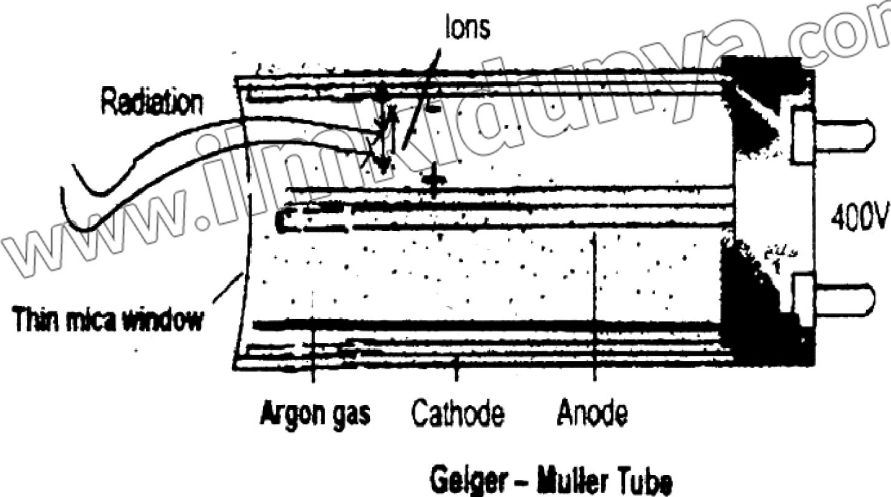
Principle:

The discharge in the tube results from the ionization produced by the incident radiation.

Construction and working of Geiger-Muller counters:

i. It consists of a stiff central wire acting as an anode in hollow metal cylinder acting as a cathode filled with a suitable mixture of gas at about 0.1 atmospheric pressure. One end of the tube has a thin mica window to allow the entry of α or β -particles and other end is sealed by non-conducting material and carries the connecting pins for the two electrodes.

ii. A high potential difference, (about 400 V for neon-bromine filled tubes) but slightly less than that necessary to produce discharge through the gas is maintained between the electrodes.



iii. When radiation enters the tube, ionization is produced. The free electrons are attracted towards the positively charged central wire. As they are accelerated towards the wire by a strong electric field, they collide with other molecules of the gas and knock out more electrons which in turn do the same and produce a cascade of electrons that move towards the central wire. This makes a short pulse of electric current to pass through an external resistor. It is amplified and registered electronically. The counter, which also provides the power, is called a scaler.

iv. Cascade of electrons:

The cascade of electrons produced by the entry of an ionizing particle is counted as a single pulse of approximately of the same size whatever the energy or path of the particle maybe. It cannot, thus, discriminate between the energies of the incident particle as output pulses are same.

v. Time for electron pulse:

The entire electron pulse takes less than $1 \mu\text{s}$. However, positive ions, being very massive than the electrons, take several hundred times as long to reach the outer cathode. During this time, called the dead time ($\sim 10^{-4} \text{ s}$) of the counter, further incoming particles cannot be counted.

vi. When positive ions strike the cathode, secondary electrons are emitted from the surface. These electrons would be accelerated to give further spurious counts. This is prevented by mixing a small amount of quenching gas with the principal gas.

vii. **Quenching gas:**

The quenching gas must have an ionization potential lower than that of inert or principal gas. Thus, the ions of quenching gas reach the cathode before principal gas ions. When they reach near the cathode, they capture electrons and become neutral molecules. Following neutralization, the excess energy of the quenching molecules is dissipated in dissociation of the molecules rather than in the release of electrons from the cathode.

viii. Bromine gas is added to neon gas. The bromine molecules absorb energy from the ions or secondary electrons and dissociate into bromine atoms. The atoms then readily recombine into molecules again for the next pulse. The gas quenching is called self-quenching.

ix. Although all commercial Geiger tubes are self-quenched, it is common practice to use electronic quenching in addition. For this purpose, a large negative voltage is applied to the anode immediately after recording the output pulse. This reduces the electric field below the critical value for ionization by collision. The negative voltage remains until all the positive ions are collected at cathode, thus preventing secondary pulses.

Uses of Geiger Muller counter:

Geiger counter can be used to determine the range or penetration power of ionizing particles. The reduction in the count rate by inserting metal plates of varying thickness between the source and the tube helps to estimate the penetration power of the incident radiation.

Limitations of Geiger Muller counter:

Geiger counter is not suitable for fast counting, it is because of its relatively long "dead time" of the order of more than a millisecond which limits the counting rate to a few hundred counts per second. If particles are incident on the tube at a faster rate, not all of them will be counted since some will arrive during the dead time. Solid state detectors are fast enough, more efficient and accurate.

Q19: Explain briefly the construction and working of solid state detector?

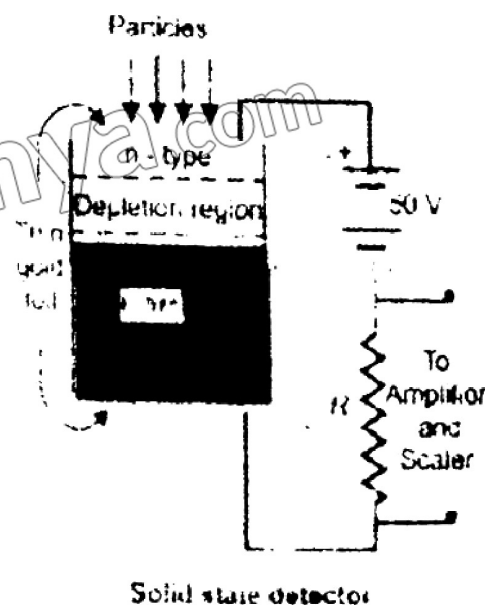
Ans: Solid state detector:

A solid state detector is a specially designed p-n Junction operating under a reversed bias in which electron-hole pairs are produced by the incident radiation to cause a current pulse to flow through the external circuit.

Construction and working of solid state detector:

i. The detector is made from a p-type silicon or germanium. An n-type thin layer is produced by doping the top surface with donor type impurity.

ii. The top and bottom surfaces are coated with a thin layer of gold to make good



conducting contact with external circuit.

iii. The combined thickness of n-type and gold layer absorbs so less energy of the incident particle that the junction may be assumed to be situated at the front surface. This is known as the surface barrier type detector.

iv. A reverse bias is applied through the two conducting layers of gold. This enlarges the charge free region around the junction called depletion region. Normally no current flows through the circuit. When an incident particle penetrates through the depletion region, it produces electron-hole pairs.

v. These mobile charge carriers move towards the respective sides due to applied electric field. This gives rise to a current in the external circuit due to which a pulse of voltage is generated across the resistance R. This pulse is amplified and registered by a scaler unit.

vi. The size of the pulse is found proportional to the energy absorbed of the incident particle. The energy needed to produce an electron-hole pair is about 3 eV to 4 eV which makes the device useful for detecting low energy particles.

Uses of solid state detector:

i. The collection time of electrons and holes is much less than gas filled counters and hence a solid state detector can count very fast.

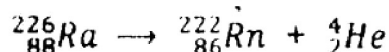
ii. It is much smaller in size than any other detector and operates at low voltage.

iii. The solid state detector is used for detecting α or β -particles but a specially designed device can be used for γ -rays.

Q20: Explain briefly nuclear reactions?

Ans: Nuclear reactions:

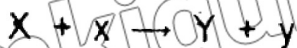
While studying radioactivity, we have seen that an α particle is emitted from radium-226 and radon-222 is obtained. This nuclear change is represented by the following equation



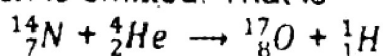
Such an equation represents a nuclear reaction. Above mentioned nuclear reaction takes place on its own accord.

i. Rutherford experiment on the nuclear reactions:

It was Rutherford who, first of all, expressed his opinion that besides natural radioactive decay processes, other nuclear reactions can also occur. A particle x is bombarded on any nucleus X and this process yields a nucleus Y and a light object y as given below



Rutherford performed an experiment on the nuclear reaction in 1918. He bombarded α -particles on nitrogen. He observed that as a result of this reaction, oxygen is obtained and a proton is emitted. That is



This reaction indicated that when an α -particle enters the nucleus of ${}^{14}\text{N}$ then an excitation is produced in it. And as a result of it ${}^{17}\text{O}$ and a proton are produced. Since the experiment of Rutherford, innumerable nuclear reactions have been observed.

Conditions for nuclear reactions:

For nuclear reactions to take place the fulfilment of certain conditions is a must.

Before and after any nuclear reaction the number of protons and neutrons must remain the same because protons and neutrons can neither be destroyed nor can they be created. We elaborate this point from the example of Rutherford's nuclear reaction of $^{14}_7\text{N}$ and ^4_2He . Here



Number of protons = $7 + 2 = 8 + 1$

Number of neutrons = $7 + 2 = 9 + 0$

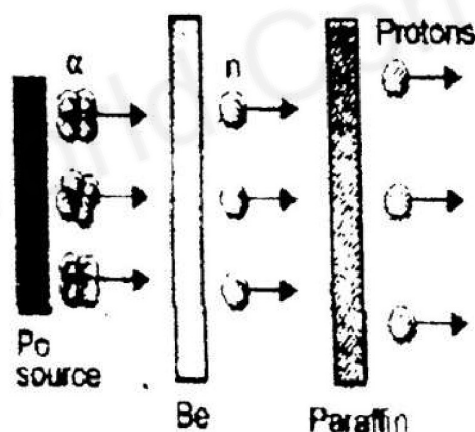
A nuclear reaction can take place only when the total energy of the reactants including the rest mass energy is equal to the total energy of the products.

Discovery of neutron by nuclear reactions:

By bombarding different elements with α -particles, protons and neutrons, many nuclear reactions have been produced. Now we describe one such nuclear reaction with the help of which James Chadwick discovered neutron in 1932. When ^9_4Be was bombarded with α -particles emitted out of $^{210}_{84}\text{Po}$, then as a result of a nuclear reaction, $^{12}_6\text{C}$ and a neutron were obtained. This reaction is shown below with an equation.



As neutron carries no charge, therefore, it presented a great amount of difficulty for its identification. Anyhow, when neutrons were passed through a block of paraffin, fast moving protons were ejected out and these were easily identified. It may be remembered that a large amount of hydrogen is present in paraffin and the nuclei of hydrogen atoms are protons. The emission of protons is the consequence of elastic collisions between the neutrons and the protons. This indicates that the mass of neutron is equal to the mass of the proton.



Note:

The discovery of neutron has brought in a revolution in nuclear reactions, as the neutrons carry no charge so they can easily enter the nucleus. Fig. shows the arrangement of Chadwick's experiment for the discovery of neutron.

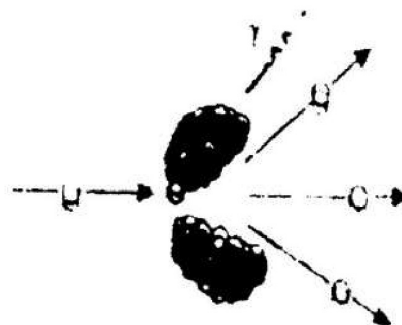
Q21: Explain briefly nuclear fission with the help of examples?

Ans: Nuclear fission:

"Such a reaction in which a heavy nucleus like that of uranium splits up into two nuclei of roughly equal size along with the emission of energy during the reaction is called fission reaction."

Explanation:

Otto Hahn and Fritz Strassmann of Germany while working upon the nuclear reactions discovered the nuclear fission. They observed that when slow moving neutrons are bombarded on $^{235}_{92}\text{U}$, then as a



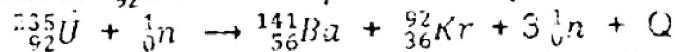
result of the nuclear reaction $^{141}_{56}\text{Ba}$ $^{92}_{36}\text{Kr}$ and an average of three neutrons are obtained.

It may be remembered that the mass of both krypton and barium is less than that of the mass of uranium.

Secondly a very large amount of energy is given out in this reaction

Example:

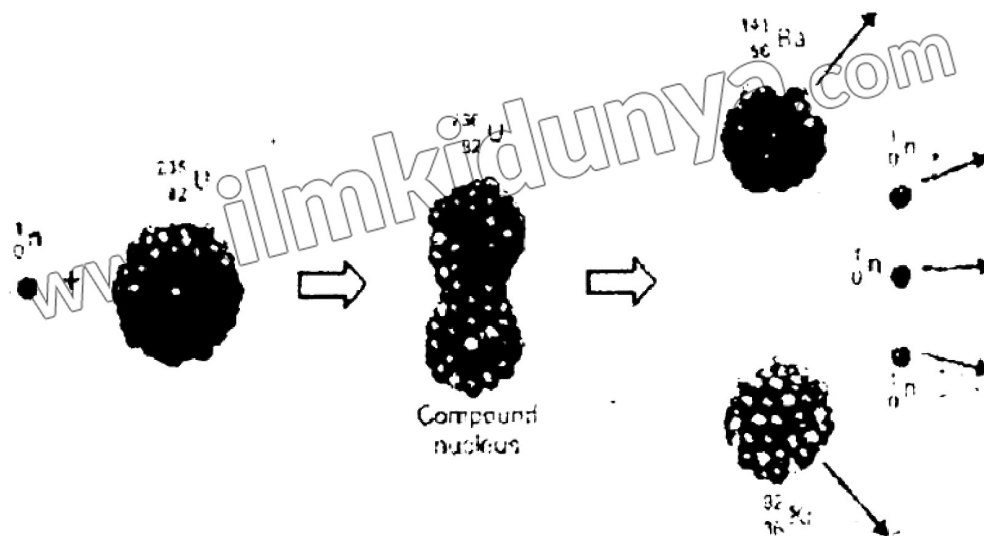
Fission reaction of $^{235}_{92}\text{U}$ can be represented by the equation



Here Q is the energy given out in this reaction. By comparing the total energy on the left side of the equation with total energy on the right side, we find that in the fission of one uranium nucleus about 200 MeV energy is given out

Binding energy:

For example the binding energy per nucleon for uranium is about 7.7 MeV

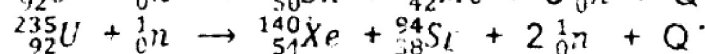
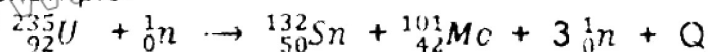


Process of Fission reaction

and the products of the fission reaction of uranium, namely barium and krypton, have binding energy of about 8.5 MeV per nucleon. Thus when a uranium nucleus breaks up, as a result of fission reaction, into barium and krypton, then an energy at the rate of $(8.5 - 7.6) = 0.9$ MeV per nucleon is given out. This means that an energy $235 \times 0.9 = 211.5$ MeV is given out in the fission of one uranium nucleus

Note:

The fission process of uranium does not always produce the same fragments (Ba, Kr). In fact any of the two nuclei present in the upper horizontal part of binding energy could be produced. Two possible fission reactions of uranium are given below as an example:



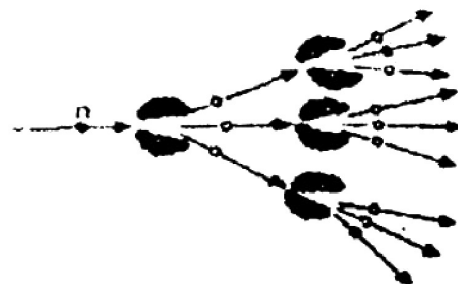
Hence in the uranium fission reaction several products may be produced. All of these products (fragments) are radioactive.

Q22: Explain briefly Fission chain reaction with the help of examples?

Ans: Fission chain reaction:

During fission reaction, a nucleus of uranium-235 absorbs a neutron and breaks into two nuclei of almost equal masses besides emitting two or three neutrons.

By properly using these neutrons fission reaction can be produced in more uranium atoms such that a fission reaction can continuously maintain itself. This process is called fission chain reaction.

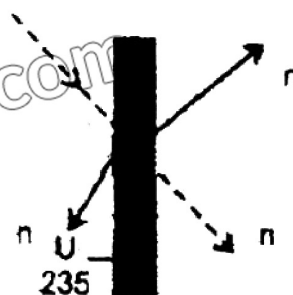


Explanation:

Suppose that we have a definite amount of $^{235}_{92}\text{U}$ and a slow neutron originating from any source produces fission reaction in one atom of uranium. Out of this reaction about three neutrons are emitted. If conditions are appropriate these neutrons produce fission in some more atoms of uranium. In this way this process rapidly proceeds and in an infinitesimal small time a large amount of energy along with huge explosion is produced. Fig is the representation of fission chain reaction.

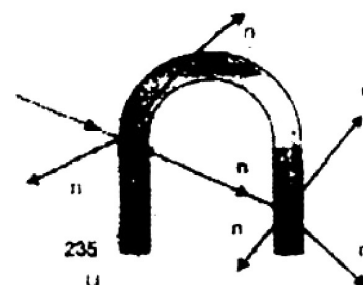
Critical volume:

Such a mass of uranium in which one neutron, out of all the neutrons produced in one fission reaction, produces further fission is called critical mass. The volume of this mass of uranium is called critical volume.



Atom bomb:

If the mass of uranium is much greater than the critical mass, then the chain reaction proceeds at a rapid speed and a huge explosion is produced. Atom bomb works at this principle.

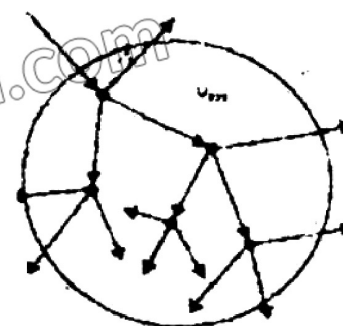


Note:

If the mass of uranium is less than the critical mass, the chain reaction does not proceed.

Energy obtained in an atomic reactor (controlled fission reaction):

If the mass of uranium is equal to the critical mass, the chain reaction proceeds at its initial speed and in this way we get a source of energy. Energy, in an atomic reactor, is obtained according to this principle. The chain reaction is not allowed to run wild, as in an atomic bomb but is controlled by a series of rods, usually made of cadmium, that are inserted into the reactor. Cadmium is an element that is capable of absorbing a large number of neutrons without becoming unstable or radioactive. Hence, when the cadmium control rods are inserted into the reactor, they absorb neutrons to cut down on the number of neutrons that are available for the fission process. In this way the fission reaction is controlled.



Q23: Explain construction and working of nuclear reactor?

Ans: Nuclear reactor:

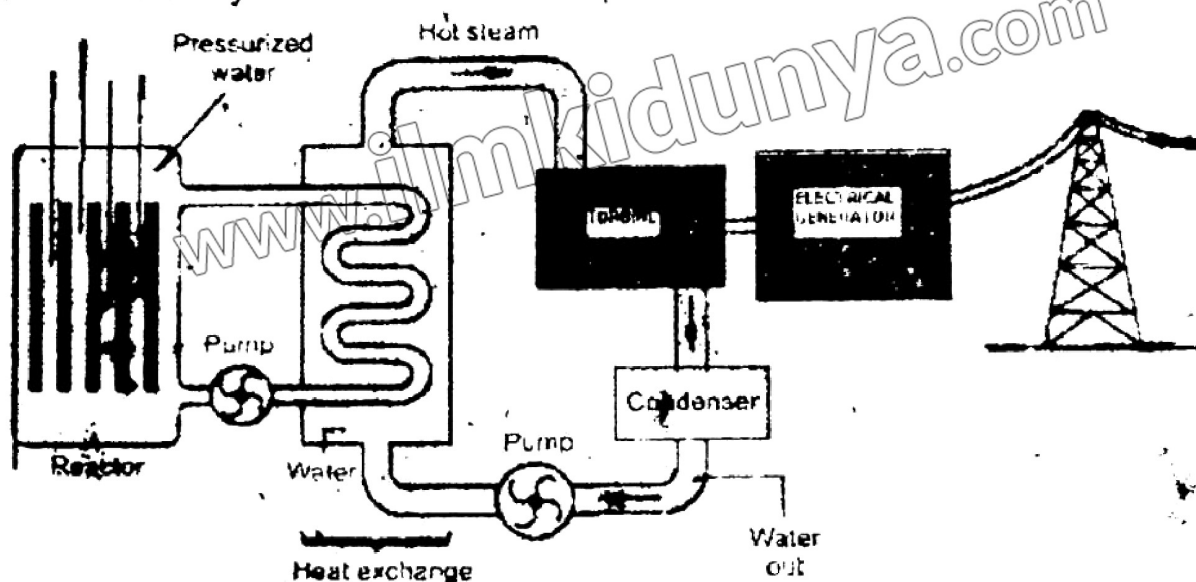
Nuclear reactor is the arrangement in which controlled nuclear fission chain reaction is carried out to use the energy produced during this process.

Nuclear reactor and furnace:

In a nuclear power station the reactor plays the same part as does furnace in a thermal power station. In a furnace, coal or oil is burnt to produce heat, while in a reactor fission reaction produces heat.

Nuclear power station:

When fission takes place in the atom of uranium or any other heavy atom, then energy at the rate of 200 MeV per nucleus is produced. This energy appears in the form of kinetic energy of the fission fragments. These fast moving fragments besides colliding with one another also collide with the uranium atoms. In this way their kinetic energy gets transformed in heat energy. This heat is used to produce steam which in turn rotates the turbine. Turbine rotates the generator which produces electricity. A sketch of a nuclear power station is shown in Fig.



Construction of nuclear reactor:

A reactor usually has four important parts. These are:

1. Core of nuclear reactor:

The most important and vital part of a reactor is called core. Here the fuel is kept in the shape of cylindrical tubes. Reactor fuels are of various types. Uranium was used as fuel in the elementary reactors. In this fuel the quantity of $^{235}_{92}\text{U}$ is increased from 2 to 4 percent. It may be remembered that the quantity of $^{235}_{92}\text{U}$ in the naturally occurring uranium is only 0.7 percent. Now-a-days plutonium-239 and uranium-233 are also being used as fuel.

2. Moderators:

The fuel rods are placed in a substance of small atomic weight, such as water, heavy water, carbon or hydrocarbon etc. These substances are called moderators. The function of these moderators is to slow down the speed of the neutrons produced during the fission process and to direct them towards the fuel.

Use of heavy water:

Heavy water, it may be remembered, is made of ${}^2_1\text{H}$, a heavy isotope of hydrogen instead of ${}^1_1\text{H}$. The neutrons produced in the fission reaction are very fast and energetic and are not suitable for producing fission in reactor fuel like ${}^{235}_{92}\text{U}$ or ${}^{239}_{94}\text{Pu}$ etc. For this purpose slow neutrons are more useful. To achieve this, moderators are used.

3. Controlled rods:

Besides moderator there is an arrangement for the control of number of neutrons, so that of all the neutrons produced in fission, only one neutron produces further fission reaction. The purpose is achieved either by cadmium or by boron because they have the property of absorbing fast neutrons. The control rods made of cadmium or boron are moved in or out of the reactor core to control the neutrons that can initiate further fission reaction. In this way the speed of the chain reaction is kept under control. In case of emergency or for repair purposes control rods are allowed to fall back into the reactor and thus stop the chain reaction and shut down the reactor.

4. Use of steam to run turbine:

Heat is produced due to chain reaction taking place in the core of the reactor. The temperature of the core, therefore, rises to about 500°C . To produce steam from this heat, it is transported to heat exchanger with the help of water, heavy water or any other liquid under high pressure. In the heat exchanger this heat is used to produce high temperature steam from ordinary water. The steam is then used to run the turbine which in turn rotates the generator to produce electricity. The temperature of the steam coming out of the turbine is about 300°C . This is further cooled to convert it into water again. To cool this steam, water from some river or sea is, generally, used. In Karachi nuclear power plant (KANUP), heavy water is being used as a moderator and for the transportation of heat also from the reactor core to heat exchanger, heavy water is used. To cool steam coming out of the turbine, sea water is being used.

Q24: Briefly describe the disposal of nuclear fuel?

Ans: Disposal of nuclear fuel:

The nuclear fuel once used for charging the reactor can keep on operation continuously for a few months. There after the fissile material begins to decrease. Now the used fuel is removed and fresh fuel is fed instead. In the used up fuel intensely radioactive substances remain. The half-life of these radioactive remnant materials is many thousand years. The radiations and the particles emitted out of this nuclear waste is very injurious and harmful to the living things. Unfortunately there is no proper arrangement of the disposal of the nuclear waste. This cannot be dumped into oceans or left in any place where they will contaminate the environment, such as through the soil or the air. They must not be allowed to get into the drinking water. The best place so far found to store these wastes is in the bottom of old salt mines, which are very dry and are thousands of metres below the surface of the Earth. Here they can remain and decay without polluting the environment.

Q25: Illustrate the types of reactors?

Ans: Types of reactors:

There are two main types of nuclear reactors. These are:

(i) Thermal reactors

(ii) Fast reactors

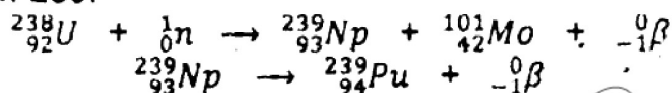
i. Thermal reactors:

a. The thermal reactors are called "thermal" because the neutrons must be slowed down to "thermal energies" to produce further fission. They use natural uranium or slightly enriched uranium as fuel. Enriched uranium contains a greater percentage of U-235 than natural uranium does.

b. There are several designs of thermal reactors. Pressurized water reactors (PWR) are the most widely used reactors in the world. In this type of reactors, the water is prevented from boiling, being kept under high pressure. This hot water is used to boil another circuit of water which produces steam for turbine rotation of electricity generators.

ii. Fast reactors:

Fast reactors are designed to make use of U-238, which is about 99% content of natural uranium. Each U-238 nucleus absorbs a fast neutron and changes to plutonium-239.



Plutonium can be fissioned by fast neutrons, hence moderator is not needed in fast reactors. The core of fast reactors consists of a mixture of plutonium and uranium dioxide surrounded by a blanket of uranium-238.

Note:

Neutrons that escape from the core interact with uranium-238 in the blanket, producing thereby plutonium-239. Thus more plutonium fuel is bred in this way and natural uranium is used more effectively.

Q26: Briefly explain fusion reaction?

Ans: Fusion reaction:

"Such a nuclear reaction in which two light nuclei merge to form a heavy nucleus is called fusion reaction".

Explanation:

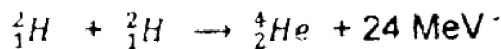
- I. During a fusion reaction some mass is lost and its equivalent energy is given out. In a fusion reaction, more energy per nucleon can be obtained as compared to the fission reaction.
- II. But unfortunately it is comparatively more difficult to produce fusion. Two positively charged light nuclei must be brought very close to one another. To do so work has to be done against the electrostatic force of repulsion between the positively charged nuclei. Thus a very large amount of energy is required to produce fusion reaction.
- III. Greater amount of energy can be obtained during a fusion reaction compared to that produced during a fission reaction, but in order to start this reaction a very large amount of energy is spent.

Note:

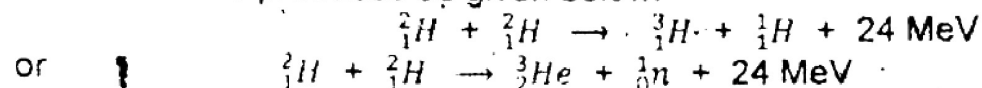
On the contrary no difficulty is faced to start the fission reaction because neutron has no charge on it and it has to face no repulsive force while reaching the nucleus.

Examples:

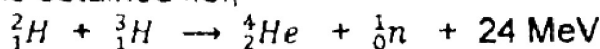
Let us now take the example of a fusion reaction when two deuterons are merged to form a helium nucleus, 24 MeV energy is released during this process i.e.,



But there is a very little chance of the formation of ${}^4_2\text{He}$ nucleus by the merger of two deuterons. The probability of occurring such a reaction is great where one proton or one neutron is produced as given below:



In both of these reactions about 1.0 MeV energy per nucleon is produced which is equal to the energy produced during fission. If ${}^2_1\text{H}$ and ${}^3_1\text{H}$ are forced to fuse then 17.6 MeV energy is obtained i.e.,



Difficulties to achieve nuclear fusion reaction:

We know that for fusion of two light nuclei the work has to be done to overcome the repulsive force which exists between them. For this the two nuclei are hurled towards one another at a very high speed. One method to do so is to give these nuclei a very large velocity with the help of an accelerator. This method has been used in the research study of nuclear fusion of ${}^2_1\text{H}$ and ${}^3_1\text{H}$. But this method of nuclear fusion for getting energy cannot be used on a large scale.

Fusion reaction by thermo-nuclear reaction:

There is another method to produce fusion reaction. It is based upon the principle that the speed of atoms of a substance increases with the increase in the temperature of that substance. To start a fusion reaction the temperature at which the required speed of the light nuclei can be obtained is about 10 million degrees Celsius. At such extraordinarily high temperature the reaction that takes place is called thermonuclear reaction. Ordinarily such a high temperature cannot be achieved. However during the explosion of an atom bomb this temperature can be had for a very short time.

Hydrogen bomb:

Until now the fusion reaction is taking place only in a hydrogen bomb. That extraordinary high temperature is obtained during the explosion of an atom bomb. due to this high temperature the fusion reaction between ${}^2_1\text{H}$ and ${}^3_1\text{H}$ sets in. In this way a very large amount of energy is given out with the explosion.

Note:

A very large amount of energy can be had from a fusion reaction, but till now this reaction has not been brought under control like a fission reaction and so is not being used to produce electricity. Efforts are in full swing in this field and it is hoped that in near future some method would be found to control this reaction as well.

Q27: Give the significance of ozone?

Ans: Significance of ozone:

Ozone on the surface of Earth is a corrosive and poisonous gas but at the height of 20-50 km from the Earth surface becomes vital to life as it absorbs almost all U V radiations which are harmful to living things.

Q28: Briefly describe the harmful effects of ultra violet radiations?

Ans: Ultra violet radiations cause

- i. Sun burn, blindness and skin cancer
- ii. Severe crop damage
- iii. decay of micro-organism
- iv. disrupt the ocean ecosystem

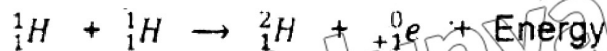
Q29: Briefly describe the nuclear reaction in sun?

Ans: Nuclear reaction in sun:

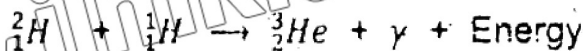
- i. The Sun is composed primarily of hydrogen. It has a little amount of helium and a slight amount of other heavy elements. A tremendous amount of energy keeps issuing out of it continuously at all times.
- ii. The temperature of its core is about 20 million degrees Celsius and its surface temperature is about 6000 degrees Celsius.

iii. p-p reaction:

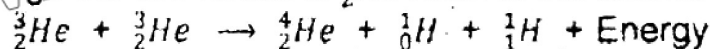
Energy of sun is due to fusion reaction called p-p reaction. During this process two hydrogen nuclei or two protons fuse to form deuteron. This reaction takes place as



- iv. With the fusion reaction of deuteron with proton, ${}^3_2\text{He}$ an isotope of helium is formed i.e.,



- v. In the last stage the two nuclei of ${}^3_2\text{He}$ react in the following manner:



In this reaction six protons take part and finally a helium nucleus and two protons are formed. That is, the result of different stages of this reaction is that four protons have formed one helium nucleus.

- vi. It has been estimated that in this p-p chain reaction, 25.7 MeV energy is given out i.e., 6.4 MeV per nucleon energy is obtained which is much greater than the energy given out per nucleon (1 MeV) during a fission reaction

Q30: What is meant by radiation exposure?

Ans: Radiation exposure:

When a Geiger tube is used in any experiment, it records radiation even when a radioactive source is nowhere near it. This is caused by radiation called background radiation. It is partly due to cosmic radiation which comes to us from outer space and partly from naturally occurring radioactive substance in the Earth's crust.

Cosmic radiation:

The cosmic radiation consists of high energy charged particles and electromagnetic radiation. The atmosphere acts as a shield to absorb some of these radiations as well as ultraviolet rays.

Depletion of ozone layer:

In recent past, the depletion of ozone layer in the upper atmosphere has been detected which particularly filters ultraviolet rays reaching us. This may result in increased eye and skin diseases. The depletion of ozone layer is suspected to be caused due to excessive release of some chemicals in the atmosphere such as

chlorofluorocarbons (CFC) used in refrigeration, aerosol spray and plastic foam industry. Its use is now being replaced by environmentally friendly chemicals.

Radioactive isotopes:

Many building materials contain small amounts of radioactive isotopes.

Radioactive radon gas:

Radioactive radon gas enters buildings from the ground. It gets trapped inside the building which makes radiation levels much higher from radon inside than outside. A good ventilation can reduce radon level inside the building.

Food containing radioactive substance:

All types of food also contain a little radioactive substance. The most common are potassium-40 and carbon-14 isotopes.

X-rays radiations:

Some radiation in the environment is added by human activities. Medical practices, mostly diagnostic X-ray probably contribute the major portion to it. It is an unfortunate fact that many X-ray exposures such as routine chest X-ray and dental X-ray are made for no strong reason and may do more harm than good. Every X-rays exposure should have a definite justification that outweighs the risk.

Radioactive waste:

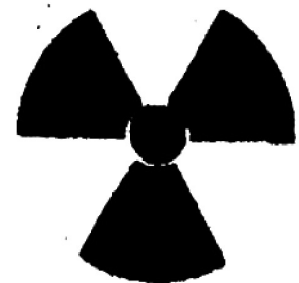
The other sources include radioactive waste from nuclear facilities, hospitals, research and industrial establishments, colour television, luminous watches and tobacco leaves.

Smoker:

A smoker not only inhales toxic smoke but also hazardous radiation.

Note:

- i. Low level background radiation from natural sources is normally considered to be harmless.
- ii. However, higher levels of exposure are certainly damaging.
- iii. We cannot avoid exposure to radiation. However, the best advice is to avoid unnecessary exposure to any kind of ionizing radiation.



Q31: Draw a symbol universally used to indicate the radioactivity?

Ans: This symbol is universally used to indicate an area where radioactivity is being handled or artificial radiations are being produced.

Q32: Briefly describe some biological effects of radiation? What are the units of radiation?

Ans: Units of radiation:

The strength of the radiation source is indicated by its activity measured in Becquerel (Bq).

Becquerel (Bq):

One Becquerel is one disintegration per second.

Curie (Ci):

A larger unit is curie (Ci) which equals 3.7×10^{10} disintegrations per second.

Dose (D):

The effect of radiation on a body absorbing it relates to a quantity called absorbed dose D defined as the energy E absorbed from ionizing radiation per unit mass m of the absorbing body

$$D = \frac{E}{m} \quad (1)$$

SI unit of radiation gray (Gy):

Its SI unit is gray (Gy) defined as one joule per kilogram.

$$1 \text{ Gy} = 1 \text{ Jkg}^{-1}$$

Old unit rad:

An old unit is rad, an acronym for radiation absorbed dose.

$$1 \text{ rad} = 0.01 \text{ Gy}$$

Biological effectiveness or RBE:

The absorbed dose is multiplied by a quality factor known as relative biological effectiveness or RBE.

Equivalent dose D_e :

The equivalent dose D_e of any absorbed radiation is defined as the product of absorbed dose and RBE of the kind of radiation being absorbed.

$$D_e = D \times \text{RBE} \quad (2)$$

SI unit of equivalent dose is sievert (Sv):

The SI unit of equivalent dose is sievert (Sv).

$$1 \text{ Sv} = 1 \text{ Gy} \times \text{RBE}$$

Rem:

An old unit, the rem is equal to 0.01 Sv.

$$1 \text{ rem} = 0.01 \text{ Sv}$$

Biological effects of radiation:

- i. Equal doses of different radiations do not produce same biological effect.
- ii. For the same absorbed dose, α -particles are 20 times more damaging than X-rays.
- iii. The effect also depends on the part of the body absorbing the radiation. For example, neutrons are particularly more damaging to eyes than other parts of the body.
- iv. The background radiation to which we are exposed, on the average, is 2 mSv per year. Doses of 3 Sv will cause radiation burns to the skin.
- v. For workers in the nuclear facilities or mines, a weekly dose of 1 mSv is normally considered safe.
- vi. The damage from α -particles is small unless the source enters the body, α and β -particles can cause redness and sores on the skin.
- vii. **Low level radiation effects:**
Some other low level radiation effects are loss of hair, ulceration, stiffening of the lungs, and a drop in the white blood cells which is followed by a sickness pattern of diarrhea, vomiting and fever known as radiation sickness.
- viii. **High level radiation effects:**
High levels of radiation may disrupt the blood cells seriously leading to diseases such as anaemia and leukaemia

Chromosome abnormalities or mutation may cause delayed genetic effects such as cancer, eye cataracts and abnormalities in the future generations. These may develop many years after exposure to harmful radiation.

Q33: Describe relative biological effectiveness (RBE)?

Ans: Relative Biological effectiveness (RBE):

Relative Biological effectiveness (RBE)	
Radiation	RBE
X-rays, γ -rays and α -particles of 30 keV or more	1.0
α - particles of less than 30 keV	1.7
Neutrons and protons below 10 MeV	10 (body) 30 (eyes)
α -particles from natural radioactivity	10
Heavy recoil nuclei	20

Q34: Briefly describe average radiation doses from a number of common sources of ionizing?

Ans: Average radiation doses from a number of common sources of ionizing:

Types of Exposure	mSv
Watching television for a year	10
Radiation from nuclear power stations for a year	10
Wearing a radioactive luminous watch for a year (now not very common)	30
Having a chest X-ray	200
Radiation from a brick house per year	750
Maximum dose allowed to general public from artificial sources per year	1000
Working for a month in a uranium mine	1000
Typical dose received by a member of the general public in a year from all sources	2500
Maximum dose allowed to workers exposed to radiation per year	50000

Q35: Illustrate the half life of different isotopes and their use also?

Ans: Half-life of isotopes:

Isotope	Half-life	Gamma energies/ MeV	Example of use
Sodium ^{24}Na	15 hours	1.37, 2.75	Plasma volume
Iron ^{59}Fe	45 hours	1.29, 1.10, 0.19	Iron in plasma
Technetium ^{99}Tc	6 hours	0.14	Thyroid uptake scan
Iodine ^{131}I	8 days	0.72, 0.64, 0.36, 0.28, 0.08	Kidney tests
Iodine ^{125}I	60 days	0.035	Plasma volume Vein flow

Q36: Write down the biological and medical uses of radiation?

Ans: Biological and medical uses of radiation:

- i. Radioisotopes are used to find out what happens in many complex chemical reactions and how they proceed.
- ii. In biology, they have helped in investigating into chemical reactions that take place in plants and animals. By mixing a small amount of radioactive isotope with fertilizer, we can easily measure how much fertilizer is taken up by a plant using radiation detector. From such measurements, farmers know the proper amount of fertilizer to use. Through the use of radiation-induced mutations, improved varieties of certain crops such as rice, chickpea, wheat and cotton have been developed.
- iii. They have improved plant structure. The plants have shown more resistance to diseases and pest, and give better yield and grain quality. Radiation is also used to treat cancers.

Q37: Describe the types of radioactive wastes?

Ans: Radioactive wastes are of three types i.e., high level, medium and low level. All these wastes are dangerous for ground water and land environment.

Q38: Briefly describe about tracer techniques?

Ans: Tracer techniques:

- i. A radioactive isotope acts as an indicator or tracer that makes it possible to follow the course of a chemical or biological process.
- ii. The technique is to substitute radioactive atoms for stable atoms of the same kind in a substance and then to follow the 'tagged' atoms with the help of radiation detector in the process.
- iii. Tracers are widely used in medicine to detect malignant tumors and in agriculture to study the uptake of a fertilizer by a plant. For example, if a plant is given radioactive carbon-14, it will use it in exactly the same way as it always uses stable carbon-12. But the carbon-14 releases β -radiations and thus by measuring radioactivity in different parts of the plant, the path taken by the carbon atoms can be known. This technique has helped to understand more elaborately the complex process of photosynthesis.
- iv. The tracer technique was also used to identify faults in the underground pipes of the fountain system of the historical Shalimar gardens of Lahore by the scientists of Pakistan Atomic Energy Commission.

Q39: How tracers are used in medical diagnostics and therapy?

Ans: Medical diagnostics and therapy:

Tracers are widely used in medicine to study the process of digestion and the way chemical substances move about in the body.

- i. Radio-iodine, for example, is absorbed mostly by the thyroid gland, phosphorus by bones and cobalt by liver. They can serve as tracers. Small quantity of low activity radioisotope mixed with stable isotope is administered by injection or otherwise to a patient and its location in diseased tissue can be ascertained by means of radiation detectors. For example, radioactive iodine can be used to check that a person's thyroid gland is working properly. A diseased or hyperactive gland absorbs more than twice the amount of normal thyroid gland. A similar method can be used to study the circulation of blood using radioactive isotope sodium-24.

ii. Experiments on cancerous cells have shown that those cells that multiply rapidly absorb more radiation and are more easily destroyed than normal cells by ionizing radiation. Radiotherapy with γ -rays from cobalt-60 is often used in the treatment of cancer. The γ -rays are carefully focussed on to the malignant tissue. Strict safety precautions are necessary for both patient and attendant medical staff.

iii. Radioactive iodine-131 is used to combat cancer of the thyroid gland. Since iodine tends to collect in the thyroid gland, radioactive isotopes lodge where they can destroy the malignant cells. In some cases encapsulated "seeds" are implanted in the malignant tissue for local and short ranged treatment.

iv. For skin cancers, phosphorus-32 or strontium-90 may be used instead. These produce β -radiation.

Note:

The dose of radiation has to be carefully controlled otherwise the radiation could do more damage than help. Patients undergoing radiation treatment often feel ill, because the radiation also damages the healthy cells.

Q40: How radiography is used in medical diagnosis?

Ans: Radiography:

i. The γ -rays radiographs are used in medical diagnosis such as internal imaging of the brain to determine precisely the size and location of a tumor or other parts of the body.

ii. Cracks or cavities in castings or pipes can also be detected by scanning. Any sudden increase in count rate indicates a cavity within the object.

iii. The gamma camera is designed to detect γ -radiations from sites in the body where a γ -emitting isotope is located. The camera can also be used to obtain a sequence of images to observe an organ such as a kidney in action.

Q41: What do you know about basic forces of nature?

Ans: Basic forces of nature:

The basic forces are:

- | | |
|-------------------------|-----------------------|
| 1. Gravitational force | 2. Magnetic force |
| 3. Electric force | 4. Weak nuclear force |
| 5. Strong nuclear force | |

Explanation:

i. The electric and magnetic forces were unified to get an electromagnetic force by Faraday and Maxwell, who were able to prove that a current is induced in a coil whenever the magnetic flux passing through the coil is changed, leaving behind four fundamental forces, the strong nuclear force, the electromagnetic force, the weak nuclear force and the gravitational force. These four fundamental forces of nature have seemed for some time quite different from one another.

ii. **Strong nuclear force:**

Despite its different effective strength, the strong nuclear force is effective only within sub-nuclear distances and therefore, confines the neutrons and protons within the nucleus.

iii. **Electromagnetic force:**

The electromagnetic force is long-range and causes all chemical reactions. It binds together atoms, molecules, crystals, trees, buildings and you. This force

acting on a microscopic level is responsible for a variety of apparently different macroscopic forces such as friction, cohesion and adhesion.

iv. **Weak nuclear force:**

The weak nuclear force is short range, like the strong nuclear force, and is responsible for spontaneous breaking up of the radioactive elements. It is a sort of repulsive force of very short range (10^{-17} m). It is usually masked by the effect of the strong and electromagnetic forces inside the nuclei.

v. **Gravitational force:**

The gravitational force, like the electromagnetic force, is again long range, extending upto and beyond the remotest stars and galaxies. It keeps you, the atmosphere and the seas fixed to the surface of the planet. It gives rise to the ocean tides and keeps the planets moving in their orbits around the Sun.

Unification of electromagnetic and weak forces:

One hundred years after the unification of electric and magnetic forces into electromagnetic force, in 1979, the physics Nobel prize was conferred on Glashow, Weinberg and Abdus Salam for the unification of electromagnetic and weak forces.

Grand unified electro-nuclear force:

It is further expected that a strong nuclear force will eventually unite with electroweak force to make up a single entity resulting in the grand unified electro-nuclear force.

Q42: Briefly describe the building blocks of matter?

Ans: Building blocks of matter:

Subatomic particles are divided into three groups.

1. Photons

2. Leptons

3. Hadrons

Explanation:

Elementary particles are the basic building blocks of matter. All photons and leptons are elementary particles. Hadrons are not elementary particles but are composed of elementary particles called quarks. Scientists now believe that all matter belongs to either the quark group or the lepton group.

Hadrons:

i. Hadrons are particles that experience the strong nuclear force. In addition to protons, neutrons and mesons are hadrons.

ii. The particles equal in mass or greater than protons are called baryons and those lighter than protons are called mesons.

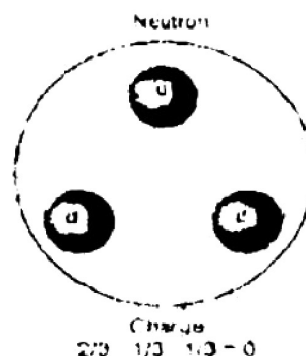
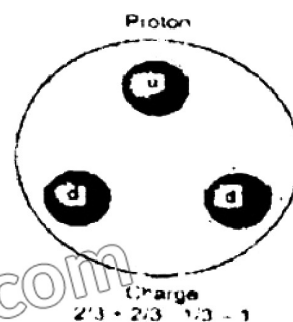
Leptons:

Leptons are particles that do not experience strong nuclear force. Electron, muons and neutrinos are leptons.

Quarks:

i. According to quark theory initiated by M. Gell-Mann and G. Zweig, the quarks are proposed as the basic building blocks of the mesons and baryons.

ii. A pair of quark and antiquark makes a meson and 3 quarks make a baryon.



- iii. It is proposed that there are six quarks, the (1) up (2) down (3) strange (4) charm (5) bottom and, (6) top. The charges on these quarks are fractional as shown in Table.

Quarks and antiquarks		
Name	Symbol	Charge
Up	u	$+\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$
Strange	s	$-\frac{1}{3}e$
Charm	c	$+\frac{2}{3}e$
Top	t	$+\frac{2}{3}e$
Bottom	b	$-\frac{1}{3}e$

Antiquarks	
\bar{u}	$-\frac{2}{3}e$
\bar{d}	$+\frac{1}{3}e$
\bar{s}	$+\frac{1}{3}e$
\bar{c}	$-\frac{2}{3}e$
\bar{t}	$-\frac{2}{3}e$
\bar{b}	$+\frac{1}{3}e$

- iv. A proton is assumed to be made up of two up quarks and one down quark as shown in Fig.
- v. The neutron is assumed to be made of one up quark and two down quarks as shown in Fig.
- vi. Currently, the hundred of hadrons can be accounted for in terms of six quarks and their antiquarks.
- vii. It is believed that quarks cannot exist on their own; their existence has been indirectly verified.

SUMMARY

1. The combined number of all the protons and neutrons in a nucleus is known as mass number and is denoted by A .
2. The protons and neutrons present in the nucleus are called nucleons.
3. The number of neutrons present in a nucleus is called its neutrons number and is denoted by N .
4. The number of protons inside a nucleus or the number of electrons outside of the nucleus is called the atomic number or the charge number of an atom and is denoted by Z .
5. Isotopes are such nuclei of an element that have the same charge number Z , but have different mass number A .

6. The mass of the nucleus is always less than the total mass of the protons and neutron that make up the nucleus. The difference of the two masses is called mass defect. The missing mass is converted to energy in the formation of the nucleus and is called the binding energy.
7. The emission of radiations (α , β and γ) from elements having charge number Z greater than 82 is called radioactivity.
8. The change of an element into a new element due to emission of radiations is called radioactive decay. The original element is called parent element and the element formed due to this decay is called daughter element.
9. Half-life of a radioactive element is that period in which half of the atoms of the parent element decay into daughter element.
10. Such a reaction in which a heavy nucleus like uranium splits up into two nuclei of equal size along with the emission of energy during reaction is called fission reaction.
11. Such a nuclear reaction in which two light nuclei merge to form a heavy nucleus along with the emission of energy is called fusion reaction.
12. The strength of the radiation source is indicated by its activity measured in becquerel. One becquerel (Bq) is one disintegration per second. A larger unit is curie (Ci) which equals 3.7×10^{10} disintegrations per second.
13. The effect of radiation on a body absorbing it relates to a quantity called absorbed dose D defined as the energy E absorbed from ionizing radiation per unit mass m of the absorbing body.
14. The basic forces are:

i. Gravitational force	ii. Electromagnetic force
iii. Weak nuclear force	iv. The strong force
15. Subatomic particles are divided into following three groups:

i. Photons	ii. Leptons	iii. Hadrons
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16. Elementary particles are the basic building blocks of matter.

SOLUTION OF EXERCISE

21.1. What are isotopes? What do they have in common and what are their differences?

Ans: Isotopes:

Isotopes are such nuclei of an element that have the same charge number Z , but have different mass number A .

Similarities and differences of isotopes:

In the nucleus of isotopes the number of protons is the same, but the number of neutrons is different.

21.2. Why are heavy nuclei unstable?

Ans: Heavy nuclei are unstable because of their low binding energy per nucleon and due to repulsive electromagnetic forces which become more and more dominant as the size of the nucleus increases. Hence a heavy nucleus is less stable.

6. The mass of the nucleus is always less than the total mass of the protons and neutron that make up the nucleus. The difference of the two masses is called mass defect. The missing mass is converted to energy in the formation of the nucleus and is called the binding energy.
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21.3. If a nucleus has a half life of 1 year, does this mean that it will be completely decayed after 2 years? Explain.

Ans: No, because an element completely decayed after an infinite time
If number of atoms initially present = N_0

After one years number of atoms remain undecayed = $\frac{N_0}{2}$

After two years number of atoms undecayed = $\frac{1}{2} \times \frac{N_0}{2} = \frac{1}{4} N_0$

Number of atoms decayed = $N_0 - \frac{1}{4} N_0 = \frac{3}{4} N_0$

Hence $\frac{3}{4}$ or 75 % of the nucleus decayed in two years.

21.4. What fraction of a radioactive sample decays after two half lives have elapsed?

Ans: If number of atoms initially present = N_0

After one years number of atoms remain undecayed = $\frac{N_0}{2}$

After two years number of atoms undecayed = $\frac{1}{2} \times \frac{N_0}{2} = \frac{1}{4} N_0$

Number of atoms decayed = $N_0 - \frac{1}{4} N_0 = \frac{3}{4} N_0$

Fraction of sample decayed = $\frac{\frac{3}{4} N_0}{N_0} \times 100 = \frac{3}{4} \times 100 = 75 \%$

Hence $\frac{3}{4}$ or 75 % of the nucleus decayed in two years.

21.5. The radioactive element $^{226}_{88}\text{Ra}$ has a half life of 1.6×10^3 years. Since the earth is about 5 billion years old, how can you explain why we still can find this element in nature?

Ans: Half life:

It is the period in which half of the radioactive element atoms decay. An element completely decayed after an infinite time.

Thus with the passage of every half life the number of atoms remaining behind becomes half of the number of atoms already present. In this way an infinite time is required for all atoms to decay. As the earth five billion years old (not infinite time) so we can still find $^{226}_{88}\text{Ra}$ element in nature.

21.6. Describe a brief account of various types of radiations with matter.

Ans: See Q13. from SHORT AND LONG QUESTIONS

21.7. Explain how α and β particles may ionize an atom without directly hitting the electrons? What is the difference in the action of the two particles for producing ionization?

Ans: Alpha particle is positively charge particle. When an alpha particle passes close to the atoms or molecules of the gas it ionizes then due to the Coulomb's attractive force. The process of ionization continues still α -particle losses its entire energy and comes to rest.

Difference in the action of α -particle and β -particle:

α -particle pulls an electron out of the atom while β -particle repels an electron out of the atom and ionizes the atom.

21.8. A particle which produces more ionization is less penetrating. Why?

Ans: A particle which produces more ionization is less penetrating because its rate of losing energy is very high so it loses its all energy in a short interval of time hence can penetrate through a very short distance in the substance.

21.9. What information is revealed by the length and shape of the tracks of an incident particle in Wilson cloud chamber?

Ans: Cloud chamber track of α -particle:

The α -particles leave thick, straight and continuous tracks due to intense ionization produced by them.

Cloud chamber track of β -particle:

β -particles form thin and discontinuous tracks extending in erratic manner showing frequent deflections.

Cloud chamber track of γ -particle:

γ -rays leave no definite tracks along their path.

Length of cloud track:

The length of the cloud tracks has been found proportional to the energy of the incident particle.

Shape of the tracks gives information about the massiveness of the particle while the length reveals the penetrating power of the incident particle.

21.10. Why must a Geiger Muller tube for detecting α -particles have a very thin window? Why does a Geiger Muller tube for detecting γ -rays not need a window at all?

Ans: As we know that penetrating power of α -particle is less than γ -rays due to these reason Alpha rays cannot penetrate through the walls of the tube so a window is required as an in left for the Alpha rays. Gamma rays, being extremely penetrating, require no such window as they can easily penetrate through the walls of the tube.

21.11. Describe the principle of operation of a solid state detector of ionizing radiation in terms of generation and detection of charge carriers.

Ans: See Q19: from SHORT AND LONG QUESTIONS

21.12. What do we mean by the term critical mass?

Ans: Critical mass:

Such a mass of uranium in which one neutron, out of all the neutrons produced in one fission reaction, produces further fission is called critical mass. The volume of this mass of uranium is called critical volume.

21.13. Discuss the advantages and disadvantages of nuclear power compared to the use of fossil fuel generated power?

Ans: Nuclear power gives much more energy than fossil fuels. Nuclear power is cheaper than fossil fuel generated power.

The nuclear power plant produces radiations which are harmful for living things. It is difficult to dispose of nuclear waste.

21.14. What factors make a fusion reaction difficult to achieve?

Ans: Difficulties to achieve nuclear fusion reaction:

We know that for fusion of two light nuclei the work has to be done to overcome the repulsive force which exists between them. For this the two nuclei are

hurled towards one another at a very high speed. One method to do so is to give these nuclei a very large velocity with the help of an accelerator. This method has been used in the research study of nuclear fusion of ${}^2_1\text{H}$ and ${}^3_1\text{H}$. But this method of nuclear fusion for getting energy cannot be used on a large scale.

Fusion reaction by thermo-nuclear reaction:

There is another method to produce fusion reaction. It is based upon the principle that the speed of atoms of a substance increases with the increase in the temperature of that substance. To start a fusion reaction the temperature at which the required speed of the light nuclei can be obtained is about 10 million degrees Celsius. At such extraordinarily high temperature the reaction that takes place is called thermonuclear reaction. Ordinarily such a high temperature cannot be achieved. However during the explosion of an atom bomb this temperature can be had for a very short time.

21.15. Discuss the advantages and disadvantages of fission power from the point of view of safety, pollution and resources?

Ans: Main advantage of fission power is the tremendous amount of energy that is given out by it. The main disadvantages involve unavailability of easily fissionable materials, and the disposal of the residue which involves extremely radioactive isotopes (nuclear waste, nuclear hazards and radiation pollution).

21.16. What do you understand by "background radiations"? State two sources of these radiations?

Ans: When a Geiger tube is used in any experiment, it records radiation even when a radioactive source is nowhere near it. This is caused by radiation called background radiation. It is partly due to cosmic radiation which comes to us from outer space and partly from naturally occurring radioactive substance in the Earth's crust.

The main sources are: distant stars, galaxies and cosmic rays.

21.17. If you swallow an α -source and a β -source, which could be more dangerous to you? Explain why?

Ans: α -source could be more dangerous. As, due to its extremely high ionizing power, it will produce more disorder in body cells than a β -source. It should also be noted that RBE for alpha is much greater than beta.

21.18. Which radiation dose would deposit more energy to your body (a) 10 m Gy to your hand (b) 1 m Gy dose to your entire body?

Ans: Dose (D):

The effect of radiation on a body absorbing it relates to a quantity called absorbed dose D defined as the energy E absorbed from ionizing radiation per unit mass m of the absorbing body.

$$D = \frac{E}{m} \quad (1)$$

Where E = total energy absorbed

And m = total mass

SI unit of radiation gray (Gy):

Its SI unit is gray (Gy) defined as one joule per kilogram.

$$1 \text{ Gy} = 1 \text{ J kg}^{-1}$$

$$1 \text{ m Gy} = 1 \times 10^{-3} \text{ Gy}$$

$$10 \text{ m Gy} = 10 \times 10^{-3} \text{ Gy}$$

By using Eq. 1

$$E_{\text{hand}} = 10 \times 10^{-3} \times m_{\text{hand}} = 0.01 \times m_{\text{hand}} \quad (2)$$

$$E_{\text{body}} = 1 \times 10^{-3} \times m_{\text{body}} = 0.001 \times m_{\text{body}} \quad (3)$$

From Eq. 2 and 3 it is clear that 10 m Gy will deposit more energy to the body

21.19. What is a radioactive tracer? Describe one application each in medicine, agriculture and industry.

Ans: Radioactive tracer:

Radioactive tracer is the radioactive isotope of an element which is used for finding faults in biological or mechanical systems.

Further See Q38: from SHORT AND LONG QUESTIONS

21.20. How can radioactivity help in the treatment of cancer?

Ans: Radioactive rays are used to destroy cancerous cells, e.g. Iodine-131 is used to destroy malignant cells which are developed in thyroid gland of a patient of cancer

Further See Q38 from Short and Long questions

SOLUTION OF EXAMPLES

Example 21.1: Find the mass defect and binding energy of the deuteron nucleus. The experimental mass of deuteron is 3.3435×10^{-27} kg.

Solution: Mass of deuteron = $m_D = 3.3435 \times 10^{-27}$ kg

Mass of proton = $m_p = 1.6730 \times 10^{-27}$ kg

Mass of neutron = $m_n = 1.6750 \times 10^{-27}$ kg

Mass defect = $\Delta m = ?$

Binding energy = B.E. = ?

Mass defect = $\Delta m = m_p + m_n - m_D$

$$\Delta m = 1.673 \times 10^{-27} + 1.675 \times 10^{-27} - 3.3435 \times 10^{-27}$$

$$\Delta m = 3.348 \times 10^{-27} - 3.3435 \times 10^{-27}$$

$$\Delta m = 4.0 \times 10^{-30} \text{ kg}$$

Binding energy = B.E. = mc^2

$$\text{B.E.} = 4.0 \times 10^{-30} \times (3.0 \times 10^8)^2$$

$$\text{B.E.} = 3.6 \times 10^{-13} \text{ J}$$

$$\text{B.E.} = \frac{3.6 \times 10^{-13}}{1.6 \times 10^{-19}} = 2250000 = 2.25 \times 10^6 \text{ eV}$$

Example 21.2: Iodine-131 is an artificial radioactive isotope. It is used for the treatment of human thyroid gland. Its half-life is 8 days. In the drug store of a hospital 20 mg of iodine-131 is present. It was received from the laboratory 48 days ago. Find the quantity of iodine-131 in the hospital after this period.

Solution: Half-life of iodine-131 = $T_{1/2} = 8$ days

Initial quantity of iodine = 20 mg

Time = $t = 48$ days

Final quantity of remaining radioactive iodine = ?

In this case $t = 48$ days = $6 \times T_{1/2}$

($\because T_{1/2} = 8$ days)

It means that $n = 6$

Now using the formula

Remaining quantity = $\left(\frac{1}{2}\right)^n \times \text{initial quantity}$

Substituting the values we have

Remaining quantity = $\left(\frac{1}{2}\right)^6 \times 20 = \frac{1}{64} \times 20 = 0.3125 \text{ mg}$ **Ans**

Example 21.3: How much energy is absorbed by a man of mass 80 kg who receives a lethal whole body equivalent dose of 400 rem in the form of low energy neutrons for which RBE factor is 10?

Solution: Mass = $m = 80 \text{ kg}$

Equivalent dose = $D_e = 400 \text{ rem} = 400 \times 0.01 \text{ Sv} = 4 \text{ Sv}$

($\because 1 \text{ rem} = 0.01 \text{ Sv}$)

RBE factor = 10

Energy absorbed = $D = ?$

The formula for the absorbed dose is

$$D = \frac{D_e}{\text{RBE}}$$

$$D = \frac{4}{10} = 0.4 \text{ Gy}$$

Note:

Since 1 Gy is 1 J kg^{-1}

Total energy absorbed by the whole body = $mD = 80 \times 0.4 \text{ Gy} = 32 \text{ J}$

SOLUTION OF PROBLEMS

21.1 Find the mass defect and the binding energy for tritium, if the atomic mass of tritium is 3.016049 u.

Solution: Mass of tritium = $m = 3.016094 \text{ u}$

Mass defect of tritium = $\Delta m = ?$

Binding energy of tritium = $BE = ?$

Mass defect = $\Delta m = Z \times m_p + (A - Z) m_n - m$

Where $m_p = \text{mass of proton} = 1.0059 \text{ u}$

$m_n = \text{mass of neutron} = 1.008665 \text{ u}$

$$\Delta m = (1 \times 1.007276 + (3 - 1) 1.008665 - 3.016049)$$

$$\Delta m = 8.5566 \times 10^{-3} \text{ u} = 0.00857 \text{ u}$$

Now Binding energy = $BE = \Delta m \times c^2$

$$BE = 0.0085 \times 1.66 \times 10^{-27} \times 9 \times 10^{16} = 0.126990 \times 10^{-11} \text{ J}$$

$$BE = \frac{0.126990 \times 10^{-11}}{1.6 \times 10^{-19}} = 0.0793687 \times 10^8 = 7.93687 \times 10^6 \text{ eV}$$

$$BE = 7.97 \text{ MeV}$$

21.2 The half life of $^{91}_{38}\text{Sr}$ is 9.70 hours. Find its decay constant.

Solution: Half life of $^{91}_{38}\text{Sr}$ = $T_{1/2} = 9.70 \text{ hrs} = 9.70 \times 3600 \text{ sec} = 34920 \text{ sec}$

Decay constant = $\lambda = ?$

$$\text{Decay constant} = \lambda = \frac{0.693}{T_{1/2}}$$

$$\lambda = \frac{0.693}{34920} = 1.9845 \times 10^{-5} = 1.984 \times 10^{-5} \text{ s}^{-1}$$

Remaining quantity = $\left(\frac{1}{2}\right)^n \times \text{initial quantity}$

Substituting the values we have

Remaining quantity = $\left(\frac{1}{2}\right)^6 \times 20 = \frac{1}{64} \times 20 = 0.3125 \text{ mg}$ **Ans**

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$$\text{Decay constant} = \lambda = \frac{0.693}{T_{1/2}}$$

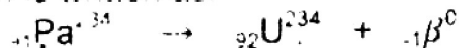
$$\lambda = \frac{0.693}{34920} = 1.9845 \times 10^{-5} = 1.984 \times 10^{-5} \text{ s}^{-1}$$

21.3 The element ${}_{91}\text{Pa}^{234}$ is unstable and decays by β -emission with a half-life 6.66 hours. State the nuclear reaction and the daughter nuclei.

Solution:

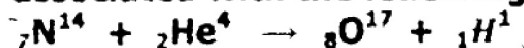
Due to β -emission the charge number increases by 1 and its mass number remains the same

The nuclear reaction is written as

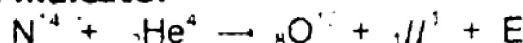


Here ${}_{92}\text{U}^{234}$ is the daughter element

21.4 Find the energy associated with the following reaction:



What do negative sign indicate?



$$E = ?$$

Total mass of the reactants on amu unit is given by

Mass of reactants = mass of ${}_{7}\text{N}^{14}$ + mass of ${}_{2}\text{He}^4$

$$= 14.0031 + 4.002603 = 18.005703 = 18.0057 \text{ u}$$

Mass of products = mass of ${}_{8}\text{O}^{17}$ + mass of ${}_{1}\text{H}^1$

$$= 16.9991 + 1.0078 = 18.0069 \text{ u}$$

Difference of masses = Δm = mass of reactants - mass of products

$$= 18.0057 \text{ u} - 18.0069 \text{ u} = -0.0012 \text{ u}$$

Since $1 \text{ u mass} = 931 \text{ MeV energy}$

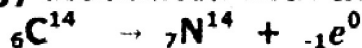
$$-0.0012 \text{ u} = (-0.0012) (931) \text{ MeV}$$

$$E = -0.0012 \times 931 = -1.12 \text{ MeV}$$

Note:

The negative sign indicates that the reaction is only possible when 1.12 MeV which is equivalent to 0.0012 u is to be added to the reactant

21.5 Determine the energy associated with the following reaction:



Solution: ${}_{6}\text{C}^{14} \rightarrow {}_{7}\text{N}^{14} + {}_{-1}\text{e}^0$

$$E = ?$$

Mass of reactants = mass of ${}_{6}\text{C}^{14}$ = 14.0077 u

Mass of products = mass of ${}_{7}\text{N}^{14}$ + mass of ${}_{-1}\text{e}^0$

$$= 14.0031 + 0.00055 = 14.00365 \text{ u}$$

Difference of masses = Δm = mass of reactants - mass of products

$$= 14.0077 \text{ u} - 14.00365 \text{ u} = 0.00405 \text{ u}$$

Since $1 \text{ u mass} = 931 \text{ MeV energy}$

$$0.00405 \text{ u} = (0.00405) (931) \text{ MeV}$$

$$E = 0.00405 \times 931 = 3.77 \text{ MeV}$$

Note:

The positive sign shows that 3.77 MeV energy will be released in this reaction.

21.6 If ${}_{92}\text{U}^{233}$ decays twice α -emission, what is the resulting isotope?

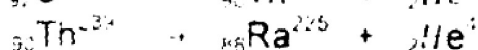
Solution:

In α -emission the atomic number Z decreased by 2 and mass number 'A' decreased by 4

During first decay:

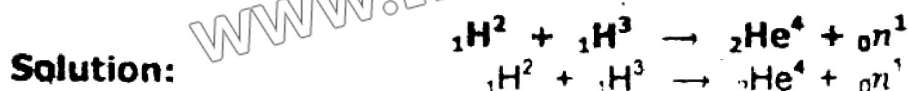


During second decay:



If ${}_{92}\text{U}^{233}$ decays twice by α -emission then radium ${}_{88}\text{Ra}^{225}$ is the resulting isotope because it is the charge number (88) of radium.

21.7 Calculate the energy (in MeV) released in the following fusion reaction:



$$E = ?$$

$$\begin{aligned}\text{Mass of reactants} &= \text{mass of } {}_1\text{H}^2 + \text{mass of } {}_1\text{H}^3 \\ &= 2.014102 + 3.01603 = 5.030132 \text{ u}\end{aligned}$$

$$\begin{aligned}\text{Mass of products} &= \text{mass of } {}_2\text{He}^4 + \text{mass of } {}_0n^1 \\ &= 4.002603 + 1.008665 = 5.011268 \text{ u}\end{aligned}$$

$$\begin{aligned}\text{Difference of masses} &= \Delta m = \text{mass of reactants} - \text{mass of products} \\ &= 5.030132 \text{ u} - 5.011268 \text{ u} = 0.018864 \text{ u}\end{aligned}$$

$$\text{Since } 1 \text{ u mass} = 931 \text{ MeV energy}$$

$$0.018864 \text{ u} = (0.018864) (931) \text{ MeV}$$

$$E = 0.018864 \times 931 = 17.6 \text{ MeV/event}$$

21.8 A sheet of lead 5.0 mm thick reduces the intensity of beam of γ -rays by a factor 0.4. Find half value thickness of lead sheet which will reduce the intensity to half of its initial value.

Solution: Thickness $= x_1 = 5 \text{ mm} = 5 \times 10^{-3} \text{ m}$

$$I_1 = 0.4 I_0$$

$$I_2 = 0.5 I_0$$

$$x_2 = ?$$

Intensity of γ -rays decreases exponentially with thickness is:

$$I = I_0 e^{-\mu x}$$

$$\Rightarrow I_1 = I_0 e^{-\mu x_1} \quad (\because I_1 = 0.4 I_0)$$

$$0.4 I_0 = I_0 e^{-\mu x_1}$$

$$0.4 = e^{-\mu x_1}$$

Taking natural log on both sides we get,

$$\ln(0.4) = -\mu x_1 \quad (1)$$

Similarly

$$I_2 = I_0 e^{-\mu x_2}$$

$$\Rightarrow 0.5 I_0 = I_0 e^{-\mu x_2}$$

$$0.5 = e^{-\mu x_2}$$

Taking natural log on both sides we get,

$$\ln(0.5) = -\mu x_2 \quad (2)$$

Dividing eq. (1) by (2) we get

$$\frac{\ln 0.4}{\ln 0.5} = \frac{-\mu x_1}{-\mu x_2}$$

$$\Rightarrow \frac{0.916}{0.693} = \frac{x_1}{x_2}$$

$$x_2 = \frac{0.693}{0.916} x_1$$

By putting the value of x_1 we get,

$$x_2 = \frac{0.693}{0.916} \times 5 \times 10^{-3} = 0.7565 \times 5 \times 10^{-3} = 3.7827 \times 10^{-3} \text{ m}$$

$$x_2 = 3.79 \text{ mm}$$

21.9 Radiation from a point source obeys the inverse square law. If the count rate at a distance of 1.0 m from Geiger counter is 360 counts per minute. What will be its count rate at 3.0 m from the source?

Solution: $d_1 = 1 \text{ m}$
 Count rate $= I_1 = 360 \text{ counts per min}$
 $d_2 = 3 \text{ m}$
 Count rate $= I_2 = ?$

Since count rate is inversely proportional to the square of the distance from the point source therefore

$$I_1 \propto \frac{1}{d_1^2}$$

So $I_1 = \frac{K}{d_1^2} \dots\dots\dots (1)$

Similarly $I_2 = \frac{K}{d_2^2} \dots\dots\dots (2)$

Dividing eq. (2) by eq. (1) we get,

$$\frac{I_2}{I_1} = \frac{K/d_2^2}{K/d_1^2}$$

$$\frac{I_2}{I_1} = \frac{d_1^2}{d_2^2}$$

$$I_2 = \frac{d_1^2}{d_2^2} \times I_1 \dots\dots\dots (3)$$

Using values in equation (3) we get

$$I_2 = \frac{360 \times (1)^2}{(3)^2} = 40 \text{ counts / minutes}$$

21.10 A 75 kg person receives a whole body radiation dose of 24 m-rad, delivered by α -particles for which RBE factor is 12. Calculate

- (a) the absorbed energy in Joules, and
 (b) the equivalent dose in rem.

Solution: Mass $= m = 75 \text{ Kg}$
 RBE factor $= 12$
 Radiation dose $= D = 24 \text{ m-rad} = 24 \times 10^{-3} \text{ rad}$

(a) $E \text{ (in J)} = ?$

(b) $D_e \text{ (in rem)} = ?$

(a) Since $D = \frac{E}{m}$
 $E = m \times D$

$$E = 75 \times 24 \times 10^{-5} = 1800 \times 10^{-5} = 18 \times 10^{-3} \text{ J} = 18 \text{ mJ}$$

(b) For equivalent dose in terms of absorbed dose is

$$D_e = \text{RBE} \times D \dots\dots\dots (1)$$

Since $D = 24 \times 10^{-3} \text{ rad}$

But, $1 \text{ rad} = 0.01 \text{ Gy}$

$$\Rightarrow D = 24 \times 10^{-3} \times 0.01 = 24 \times 10^{-5} \text{ Gy}$$

By using the values of D and RBE in equation (1) we get,

$$D_e = 12 \times 24 \times 10^{-5} = 288 \times 10^{-5} \text{ sv}$$

$$D_e = 288 \times 10^{-5} = 0.288 \times 10^{-2} \text{ sv}$$

$$D_e = 0.29 \text{ rem}$$

$$(\because 1 \text{ sv} = \text{RBE} \times 1 \text{ Gy})$$

$$(\because 1 \text{ rem} = 10^{-2} \text{ sv})$$